Universiteit van Amsterdam
institute *for* logic, language *and* computation
department *of* philosophy

proceedings of THE 11th Amsterdam Colloquium

Paul Dekker • Martin Stokhof • Yde Venema (eds.)

Paul Dekker

Proceedings of the

Eleventh Amsterdam Colloquium

institute for logic, language and computation

For further information about ILLC-publications, please contact

Institute for Logic, Language and Computation
Universiteit van Amsterdam
Plantage Muidergracht 24
1018 TV Amsterdam
phone: +31-20-5256090
fax: +31-20-5255101
e-mail: illc@wins.uva.nl

Proceedings of the Eleventh Amsterdam Colloquium

December 17 — 20, 1997

Paul Dekker, Martin Stokhof,
Yde Venema (eds.)

ILLC/Department of Philosophy
University of Amsterdam

Printed by Print Partners, Ipskamp
Cover design by drukkerij Malden
ISBN: 90 - 74795 - 90 - 0

Preface

The 1997 edition of the Amsterdam Colloquium is the eleventh installment in a series which started in 1976. Originally, the Amsterdam Colloquium was an initiative of the Department of Philosophy. Since 1984 the Colloquium is organized by the Institute for Logic, Language and Computation (ILLC), in which staff from the Department of Mathematics and Computer Science, the Department of Philosophy, and the Department of Computational Linguistics, all of the University of Amsterdam, cooperate.

For the organization of the Eleventh Amsterdam Colloquium financial support was received from the Royal Dutch Academy of Sciences (KNAW), the Department of Philosophy of the University of Amsterdam, the Dutch Graduate School in Logic (OZSL), the Foundation for Language, Speech and Logic (TSL) of the Netherlands Organization for Scientific Research (NWO), the European Association for Logic, Language and Information (FoLLI), and the project 'Logic in Communication' (funded by the Spinoza Award of Johan van Benthem), all of which is gratefully acknowledged.

These proceedings contain almost all contributions to the two workshops which take place during the Colloquium, on 'Games in Logic' and 'Topic and Focus', and to the general program. Missing is the paper presented by Arnis Vilks. The copyright resides with the individual authors.

The organizers would like to thank the members of the program committees:

- Workshop 'Topic and Focus': Jeroen Groenendijk, Barbara H. Partee, Mats Rooth, Arnim von Stechow, and Anna Szabolcsi.
- General Program: Renate Bartsch, Johan van Benthem, Gennaro Chierchia, Peter van Emde Boas, Hans Kamp, Manfred Krifka, Lawrence S. Moss, Barbara H. Partee, Hans Rott.

Paul Dekker
Martin Stokhof
Yde Venema
Amsterdam, December 1997

Contents

Games in the Semantics of Programming Languages

Samson Abramsky
Department of Computer Science
University of Edinburgh

1 Introduction

Mathematical models of computation, from the λ-calculus to PRAM's, have played a key role in the development of software technology, from programming languages to the design and analysis of algorithms. The first generation of models of computation (*c.* 1950–1980) were *functional* in character; that is, they abstracted the behaviour of a program as the computation of a function. This was an appropriate abstraction in the era of batch processing, and provided a good basis for the formalization of the *correctness* of such programs with respect to their specifications, and of the *computational complexity* of algorithmic problems.

Meanwhile, Information Technology had progressed from batch processing through multi-tasking operating systems to distributed systems and on to today's Internet. The focus has correspondingly shifted, from stand-alone *programs* to *systems*, and from *computation* to *interaction*. Stand-alone programs computing functions are now seen as (very) special cases of a wider class of behaviours, in which the components of a complex system of concurrently executing agents interact with each other to achieve some global effect. On a "macro" scale, this description evidently fits today's distributed transactions across the Internet; but on a "micro" scale, it is equally true of how functional computations are ultimately realized, whether in software or in hardware.

The challenge has then been to find models of computation which take interaction as their basic ingredient, and which combine sufficient expressive power to yield faithful descriptions of the wealth of phenomena arising from contemporary developments in IT, with sufficient mathematical structure and tractability to provide a basis for the formal analysis of such systems. An additional, and no less important goal is to address seriously the issue of *doing the fundamental science of complex interacting systems.*

The fundamental character of this challenge is indicated by the following observation. The notions of *function*, *set* and *algorithm* were available "off-the-shelf" from mathematics and logic for use in computer science. By contrast, there is no adequate pre-existing theory of processes, interaction, information flow etc. on which these "second-generation" models can build. Rather, their most basic task is precisely to give a non-trivial analysis of these concepts.

Game Semantics

Game semantics has had a fairly lengthy history in logic, with pioneering work done by Lorenzen in the 1950's [Lor60]. The basic idea is to interpret a formula as a two-person game (played between the "Proponent" asserting the thesis, and the "Opponent" seeking to refute it), and a *proof* of the formula as a *winning strategy* for Proponent. Significant further contributions were made by Joyal [Joy77], who organized Conway's games into a category, and by Blass [Bla93], who gave a game semantics for Girard's Linear Logic.

In joint work with Radha Jagadeesan in 1992 [AJ92], a number of key ideas were introduced:

- A "dictionary" between the concepts of game semantics, and those of process models of computation, in which the Player or Proponent is interpreted as the *System* being modelled, and the Opponent as its *Environment*. The interaction between system and environment is modelled by the idea of a *play* of the game. The significance of game semantics as a computational model is then apparent; it models interaction in an intrinsic fashion. In fact game semantics can be seen as a key *refinement* of the process models which had been previously considered; the refinement being that the distinction between System and Environment is made explicit, and used as a key for eliciting much of the mathematical structure. This (apparently) simple step has proved to be almost "unreasonably effective".

- Based on this distinction, precise technical links were made between constructions in game semantics and process models. Most importantly, composition of strategies (roughly, "playing one strategy off against another") was formalized as "parallel composition plus hiding", following the process interpretation of Cut-elimination in Linear Logic previously given in my work on "Proofs as Processes" [Abr94]. This has proved to be an effective and tractable formalization, which has been a basic tool in the subsequent fine-grained analysis of models based on games.

- An important difference from the previous literature from Logic on game semantics was the insistence on giving a free-standing, thoroughly semantic, compositional account. This is not a trivial matter—Blass' game semantics had a non-associative composition, for example. This insistence on the semantic approach, and on analyzing the structure of categories of games, has been fundamental to later work.

- Using the above tools, a result on *Full Completeness* for the multiplicative fragment of Linear Logic was proved. More important than the result itself was the basic paradigm which was established. Traditional completeness theorems in logic have focussed on characterizing *provability* by validity in some model or class of models. The focus from the point of view of computation or proof theory is on the proofs themselves as mathematical objects, rather than on the mere fact of provability. The idea of full completeness is to have a model given by purely semantic means (i.e. independently of the syntax) such that every element of the model is the denotation of some proof (this can be stated in terms of the *fullness* of the functor from the free category based on the syntax, hence the name). This result made it plausible that game semantics could provide a powerful tool for addressing *full abstraction problems* for the semantics of programming languages. Full completeness is also of considerable interest for logic itself, and in fact this paper spawned a (still-growing) literature on full completeness results for the same or similar fragments of Linear Logic with respect to a variety of models [HO92, Loa94, BS96].

Full Abstraction for PCF

Motivated by the full completeness results, it became of compelling interest to re-examine perhaps the best-known "open problem" in the semantics of programming languages, namely the "Full Abstraction problem for PCF", using the new tools provided by game semantics.

PCF is a higher-order functional programming language; modulo issues of the parameter-passing strategies, it forms a fragment of any programming language with higher-order procedures (which includes any reasonably expressive object-oriented language). The aspect of the Full Abstraction problem I personally found most interesting was: to construct a syntax-independent model in which every element is the denotation of some program (note the analogy with full completeness, whose definition had in turn been motivated in part by this aspect of full abstraction). This is not how the problem was originally formulated, but by "general abstract nonsense", given such a model one can always quotient it to get a fully abstract model in the original sense. The seminal papers on PCF by Milner and Plotkin appeared in 1977 [Mil77, Plo77]; and although much important work was done on the full abstraction problem, it had not proved possible to construct a fully abstract model by syntax-independent means.

In 1993 fully abstract models for PCF based on game semantics were constructed, independently, by Abramsky, Jagadeesan and Malacaria [AJM96]; Hyland and Ong [HO96]; and Nickau. This was a striking illustration of the effectiveness of the tools provided by game semantics in making a fine-grained analysis of subtle computational notions which had eluded previous attempts. In effect, these models interpreted higher-order functional programs as certain interactive processes (i.e. strategies for certain games corresponding to the types of PCF). This was not new in itself (for example, Milner had given mappings of the λ-calculus into his π-calculus). What *was* new was the precise characterization of exactly which such processes were in the image of the interpretation, the characterization moreover being in terms of "local", compositional properties (the two key ones being "history-freeness" or "innocence", i.e. a constraint on the information available to a strategy at any given stage in a computation; and "well-bracketedness", expressing that the control flow followed a properly nested stack discipline. These properties are *local* in that they are properties either of single "runs" or "plays", or at most of two plays at a time.) But was this to prove an isolated result?

The semantic cube

Over the past three years, a substantial further development of the application of games to the semantics of programming languages has taken place. Much of this can be organized around a "semantic cube" first suggested in [AM97a], and later elaborated in my Marktoberdorf lectures and other work. Here we only discuss two dimensions—a diamond rather than a cube.

The idea is that a "space of programming languages" is articulated as a family of extended typed λ-calculi. This gives rise to a "syntactic cube", whose "origin" is a purely functional language; various "orthogonal" extensions are considered, such as local state (e.g. **ref**-types), or non-local control operators (e.g. **call-cc** or exceptions). The corresponding semantic cube has the highly constrained model used to give the fully abstract model for PCF (which extends to much richer functional languages [M96]), at the origin; while the various language extensions are mirrored by relaxation of the various (independent) semantic constraints on languages which were used to capture the purely functional model. In particular, local state is captured simply by allowing fully history-sensitive strategies, while non-local control is captured by relaxing the well-bracketing constraint.

A series of results [AM97a, AM97b, AM97c, Lai97, HY97] have shown that the correspondence between the syntactic and semantic cubes is indeed exact in the sense that the semantic models are fully abstract for the corresponding languages. A remarkable and unexpected feature of these results is that in each case definability for the model of the extended language is proved by using a technique of *factorization theorems*. That is, one shows that every strategy in the larger (less constrained) space factors by a constrained strategy through a particular, "generic" unconstrained strategy. In the case of local state, this will be the strategy interpreting **newref**, while for non-local control it will be **call-cc**. This can be seen as a kind of "semantic normal form", and it immediately yields definability for the model of the extended language by reduction to definability in the restricted language. Thus the original result for PCF proves to be the lynch-pin for a whole range of results for much richer languages.

Strachey's programme

To put these results in context, it is worth recalling the programme for a Mathematical Theory of Programming Languages mapped out by the pioneer Christopher Strachey in [MS76]. Strachey's specific goal in that work was to give a precise mathematical account of a wide-spectrum modern programming language, which would provide a rigorous basis for software engineering. A reasonable restatement of this programme in current terms might be: *to give a fully abstract model of Standard ML* (or better, for a meta-language adequate to describe Standard ML). This has been a goal which has seemed well out of reach for the 20 years following the appearance of Strachey's monograph; the methods needed to build a fully abstract model of even the functional subset of such a meta-language were lacking; while getting a fully abstract model e.g. for local state was seen as a difficult problem even modulo a fully abstract model for PCF.

This landscape has been transformed by the recent results on game semantics. We are now well on the way to completing the version of Strachey's programme stated above.

Recently, in joint work with Kohei Honda and Guy McCusker, we have extended the analysis of local state to general reference types, resulting in a fully abstract model for a call-by-value λ-calculus with general **ref**-types. This was the major remaining step towards an analysis of Core ML. Combining this with the impressive recent progress made by my student Jim Laird in analyzing the "control axis" of the semantic cube, the goal of obtaining a fully abstract model for Core ML is now well in sight. Given the structure of factorization theorems with respect to sub-models accompanying these results, it should be possible to give a rather comprehensive and highly articulated account of the entire "space" of programming languages between the purely functional fragment and full Core ML.

The analysis of general reference types is of considerable interest in itself. It carries much of the same force as "mobility" in the context of Milner's π-calculus. Of particular interest is that the model is quite different in character from those previously proposed for references or for names as in the π-calculus. References are analyzed in terms of information flow; a reference "is" a strategy for connecting up readers with writers. The ramifications of this remain to be explored.

References

[AJM96] S. Abramsky, R. Jagadeesan, and P. Malacaria. Full abstraction for PCF. Submitted for publication, 1996.

[AM97a] S. Abramsky and G. McCusker. Linearity, Sharing and State. In *Algol-like languages*, ed. P. O'Hearn and R. D. Tennent, 317–348, Birkhauser 1997.

[AM97b] S. Abramsky and G. McCusker. Full Abstraction for Idealized Algol with Passive Expressions. Submitted for publication, 1997.

[AM97c] S. Abramsky and G. McCusker. Call-by-value games. In *Proceedings of CSL '97*, 1997.

[AJ94] S. Abramsky and R. Jagadeesan. New Foundations for the Geometry of Interaction. *Information and Computation*, 111(1), (1994), 53–119.

[AJ92] S. Abramsky and R. Jagadeesan. Games and Full Completeness for Multiplicative Linear Logic", *Journal of Symbolic Logic*, (1994), vol. 59, no. 2, 543–574.

[Abr94] S. Abramsky. Proofs as Processes. *J. Theoretical Computer Science* 135, (1994), 5–9.

[Abr96] S. Abramsky. Retracing some paths in process algebra. In *CONCUR '96: Concurrency Theory, 7th International Conference*. U. Montanari and V. Sassone, eds. (Springer-Verlag) 1996, 1–17.

[BHA85] G. Burn, C. Hankin and S. Abramsky. Strictness Analysis for Higher Order Functions. *Science of Computer Programming* 7, (1986), 249–278.

[AGN97a] S. Abramsky, S. Gay and R. Nagarajan. Interaction Categories and the Foundations of Typed Concurrent Programming. In *Proceedings of the 1994 Marktoberdorf Summer Sxhool on Deductive Program Design*, M. Broy, ed. (Springer-Verlag) 1996, 35–113.

[AGN97b] S. Abramsky, S. Gay and R. Nagarajan. Specification Structures and Propositions-as-Types for Concurrency. In *Logics for Concurrency: Structure vs. Automata—Proceedings of the VIIIth Banff Higher Order Workshop*, G. Birtwistle and F. Moller, eds. (Springer-Verlag) 1996, 5–40.

[Abr97] S. Abramsky. Axioms for Full Abstraction and Full Completeness. Submitted for publication, 1996.

[AR97] S. Abramsky and J. Rosicky. **SProc** as a final coalgebra. Submitted for publication, 1995.

[Bla93] A. Blass. A Game Semantics for Linear Logic. Annals of Pure and Applied Logic 56, 1993.

[BS96] R. Blute and P. J. Scott. Linear Lauchli Semantics. Annals of Pure and Applied Logic, 1996.

[HY97] K. Honda and N. Yoshida. Game-theoretic analysis of call-by-value computation. In *Proceedings of ICALP '97*.

[HO92] M. Hyland and C.-H. L. Ong. Fair Games and Full Completeness for Multiplicative Linear Logic without the MIX rule. Unpublished Manuscript, 1992.

[HO96] M. Hyland and C.H. L. Ong. On full abstraction for PCF. Submitted for publication, 1996.

[Joy77] A. Joyal. Remarques sur la théorie des jeux a deux personnes. Gazette des sci. math. du Quebec, 1,4 1977.

[Lai97] J. Laird. Full abstraction for functional languages with control. In *Proceedings of LiCS '97.*

[Loa94] R. Loader. Linear Logic, Totality and Full Completeness. In *Proceedings of LiCS '94.*

[Lor60] P. Lorenzen. Logik und Agon. In *Atti Congr. Internat. di Filosofia*, vol. 4, Sansoni, Firenze, 1960.

[M96] G. McCusker. Games and Full Abstraction for a functional meta-language with recursive types. Ph.D. thesis, University of London, 1996.

[MS76] R. Milne and C. Strachey. A Theory of Programming Language Semantics. Chapman and Hall, 1976.

[Mil77] R. Milner. Fully Abstract Models for Typed λ-calculi. *Theoretical Computer Science* 4:1–22, 1977.

[Plo77] G. Plotkin. LCF Considered as a Programming Language. *Theoretical Computer Science* 5:223–255, 1977.

Games in Algebraic Logic

Robin Hirsch (University College London)
Ian Hodkinson (Imperial College London)

In 1860, Augustus de Morgan published [DeM60], thereby launching an investigation into the algebra of relations. This developed into the subject now called *Algebraic Logic*, though in the 19th century it was simply thought of as mathematical logic. This work, along with Frege's quantifier logic, became the foundation of modern logic and model theory.

In De Morgan's writing there is no sharp separation of philosophy and mathematics and the central problem for him was to unveil the laws of rational thought. Of course the word 'rational' is critical and problematic here: he did not wish to consider how an insane person might think, nor the effect of one's mood on the thought process, nor any subjective features of thinking. Rational thought is considered here as a purely objective process, quite independent from the real cognitive process — a strange concept admittedly, but a pervasive idea in the philosophy of mathematics. De Morgan was particularly interested in discovering the principles of everyday thinking and of mathematical argument.

Two authors influenced him greatly: Aristotle and Boole. Aristotle's syllogism had held sway for 2000 years. Indeed Kant [Kan72] had argued that

> Since Aristotle's time Logic has not gained much in extent, as indeed nature forbids it should. ...Aristotle has omitted no essential point of the understanding; we have only become more accurate, methodical, and orderly.

But De Morgan was among a number of philosophers who found the Aristotelian syllogism inadequate to model the laws of thought. Consider the following quote from De Morgan

> Accordingly, all logical relation is affirmed to be reducible to *identity* A is A, to *non-contradiction*, Nothing both A and not-A, and to *excluded middle*, Everything either A or not-A. These three principles, it is affirmed, dictate all the forms of inference, and evolve all the canons of syllogism. I am not prepared to deny the truth of either of these propositions, at least when A is not self-contradictory, but I cannot see how, alone, they are competent to the functions assigned. I see that they distinguish truth from falsehood: but I do not see that they, again alone, either distinguish or evolve one truth from another. Every transgression of these laws is an invalid inference: every valid inference is not a transgression of these laws. But I cannot admit that every thing which is not a transgression of these laws is a valid inference. And I cannot make out how just the only propositions which are true of all things conceivable can *be* or *lead to* any distinction between one thing and another. I believe these three principles to be of the soil, and not of the seed, though the seed may possess some materials of the soil; of the foundation, not of the building, though the bricks may partake of the nature of the foundation; of the rails, not of the locomotive, though both may have iron in their structure.
>
> The canons of ordinary syllogism cannot be established without help from our knowledge of the *convertible* and *transitive* character of identification: that is, we must know and use the properties 'A is B gives B is A' and 'A is B and B is C, compounded, give A is C'. Can these principles be established by concession of 'A is A, nothing is both A and not-A, and every thing is one or the other'?

De Morgan thought not. Of course De Morgan's writings came long before we had the Tarski semantics and a notion of completeness, but De Morgan was dissatisfied with Aristotle's syllogism because it could not prove enough and because considerations about the laws of equality led him to believe that the syllogism was inadequate for dealing with relations of rank greater than one.

The other decisive influence was George Boole, who had put forward a highly successful algebra of propositions [Boo51]. De Morgan wrote

> When the ideas thrown out by Mr Boole shall have borne their full fruit, algebra, though only founded on ideas of number in the first instance, will appear like a sectional model of the whole form of thought. Its forms, considered apart from their matter, will be seen to contain all the forms of thought in general. The anti-mathematical logician says that it makes thought a branch of algebra, instead of algebra a branch of thought. It *makes* nothing; it *finds*: and it finds the laws of thought symbolized in the forms of algebra.

De Morgan's project then, was to use an algebraic formalism, like boolean algebra, to reason about higher order relations and particularly about binary relations.

Now binary relations, which are considered by mathematicians as simply sets of pairs, have all the structure of boolean algebras: there is a smallest (empty) binary relation, a biggest binary relation (denoted 1), you can take the union and intersection of two binary relations, and you can find the complement of a binary relation r (meaning the set of all pairs which belong to 1 but not to the relation r). So all the axioms for boolean algebra still hold over a field of binary relations. But there is more: it is natural to define the *identity* relation $1' = \{(x,x) : x \in X\}$ over a domain X, the *converse* of a relation r, $\breve{r} = \{(x,y) : (y,x) \in r\}$ and the *composition* of two relations $r;s = \{(x,y) : \exists z \in X, (x,z) \in r \wedge (z,y) \in s\}$. Observe that composition gives us relativized quantification over the variable z.

In order to consider these binary relations and the new operators from the point of view of algebra, we consider a *field of binary relations*. This is just a set of binary relations containing the identity, 0 and 1, and closed under the boolean operations, converse and composition. There are many properties that any field of binary relations must satisfy: for example composition must be associative and the identity law says that $1';r = r;1' = r$ for any r. De Morgan, Peirce, Schröder and others investigated many, many axioms like this as well as additional operators that can be defined over binary relations.

Tarski re-launched the subject in the mid-twentieth century with his formalisations of relation algebra and, for n-ary relations, n-dimensional cylindric algebra [JT48, JT51, JT52, HMT]. In this formalisation, a relation algebra was defined to be any algebraic structure with the appropriate operators that obeyed the axioms mentioned above plus a few others.

Definition 1 *A* relation algebra *is a structure* $\mathcal{A} = (A, 0, 1, ., -, 1', \smile, ;)$, *where* A *is a non-empty set (the domain or universe of* $\mathcal{A}$*),* $.$ *and* $;$ *are binary functions,* $\smile$ *and* $-$ *are unary functions, and* $0, 1$, *and* $1'$ *are constants. We require that* $(A, 0, 1, ., -)$ *is a boolean algebra (so we can use* $+$ *and* $\leq$ *as abbreviations), and that the following hold, for all* $r, s, t \in A$*:*

1. $r;1' = 1';r = r$	2. $(r;s);t = r;(s;t)$
3. $r^{\smile\smile} = r$	4. $(r+s)^{\smile} = \breve{r} + \breve{s}$
5. $(-r)^{\smile} = -\breve{r}$	6. $(r;s)^{\smile} = \breve{s};\breve{r}$
7. $(r;s).\breve{t} = 0 \ \rightarrow\ (s;t).\breve{r} = 0.$	

However, although it is fairly immediate that any field of binary relations must obey these axioms and is therefore a relation algebra, it turned out that not all relation algebras are isomorphic to genuine fields of binary relations [Lyn50] (or to put it another way, not all relation algebras are *representable* as fields of binary relations). Worse, there could be no finite axiomatisation that exactly defined the representable relation algebras [Mon64]. On the other hand, the class of representable relation algebras (or cylindric algebras) was shown, by methods of universal algebra, to form a *variety* with a recursive (equational) axiomatisation [JT48]. This led to the problem of finding a nice, recursive axiomatisation of the representable algebras. Lyndon and Monk did produce recursive axiomatisations, but these were rather complex.

A game-theoretic approach to the representability problem was described in [HH97b, HH97a]. We start by considering finite directed complete graphs N where each edge (x, y) is labelled by an element $N(x, y)$ of a relation algebra $\mathcal{A}$. One can think of these graphs as candidates to be finite fragments of some representation. These graphs must obey certain consistency conditions — for any node $x \in N$, $N(x, x) \leq 1'$, and for any three nodes x, y, z of N we have $N(x, y) \cdot (N(x, z); N(z, y)) \neq 0$. If a labelled graph failed one of these conditions, it certainly could not approximate a representation. We call labelled graphs that satisfy these consistency conditions *networks*. We want to know whether a given network actually defines a representation, or at least if it approximates some finite fragment of some representation of $\mathcal{A}$.

The consistency conditions on their own do not ensure that N defines a representation, as it may contain a *defect* — perhaps there is an edge (x, y) with $N(x, y) \leq a; b$ for some elements $a, b \in \mathcal{A}$, but there is no node z of the network with $N(x, z) \leq a$ and $N(z, y) \leq b$. Such a defect means that the map $a \mapsto \{(x, y) \in N : N(x, y) \leq a\}$ cannot be an isomorphism from $\mathcal{A}$ to a field of binary relations because it does not preserve composition.

Notation: If M, N are networks we write $M \subseteq N$ and say that M is a *subnetwork* of N, or equivalently that N is an *extension* of M, if the nodes of M form a subset of those of N and for any nodes $m, m' \in M$ we have $M(m, m') \geq N(m, m')$. Think of this as meaning that N carries more information about the constraints on the nodes of M.

We define a game $G_\omega(\mathcal{A})$, in which two players build a countably infinite sequence of graphs (or networks) labelled by elements of the algebra $\mathcal{A}$, each one a subnetwork of the next. The first player ($\forall$) is trying to prove that the relation algebra has no representation (or at least that the current network does not approximate a fragment of any representation) by picking potential defects in the current network, while the second player ($\exists$) is trying to make the networks approximate a representation better and better either by repairing the defect $\forall$ has picked or by demonstrating that it is not really a defect after all. If, at any stage, $\exists$ cannot repair the defect, or if she produces a graph that fails one of the consistency conditions, then player $\forall$ wins immediately. On the other hand, if she survives each round of the game without losing, we say that player $\exists$ has won.

More precisely, in round 0, $\forall$ picks any element $a \neq 0$ in $\mathcal{A}$, and $\exists$ must respond with a network N_0 with nodes m, n such that $N_0(m, n) = a$. In round $t > 0$, if the play so far has been $N_0 \subseteq N_1 \subseteq \cdots \subseteq N_{t-1}$ (where each N_i is a network for $i < t$), then $\forall$ may pick any edge (x, y) of N_{t-1} and any pair of elements $r, s \in \mathcal{A}$. $\exists$ must respond in one of two ways. She may *reject* $\forall$'s move, by letting N_t be the same as N_{t-1} except that $N_t(x, y) = N_{t-1}(x, y) \cdot -(r; s)$. Effectively she is saying that there is no defect because the edge (x, y) is not in the binary relation $r; s$. Alternatively, she may *accept* $\forall$'s move, by choosing a network N_t with the nodes of N_{t-1} plus a single extra node z with labelling

- $N_t(x, z) = r,\ \ N_t(z, z) = 1',\ \ N_t(z, y) = s,\ \ N_t(x, y) = N_{t-1}(x, y) \cdot (r; s)$
- if $u, v \in N_{t-1}$ and $(u, v) \neq (x, y)$ then $N_t(u, v) = N_{t-1}(u, v)$
- all other labels of N_t not yet mentioned are 1.

Here, $\exists$ is repairing the defect presented to her by $\forall$. This is an example of the 'cut-and-choose' games mentioned in Wilfrid Hodges' abstract — $\forall$ *cuts* by picking nodes x, y and elements r, s and $\exists$ *chooses* by either accepting or rejecting.

A winning strategy for player $\exists$ in this game is equivalent to the representability of the algebra. We can see this, at least for countable relation algebras, by considering a play of the game in which $\forall$ picks all possible defects at some stage in the play. In this case, if $\exists$ uses her winning strategy, we can define a map h from elements of $\mathcal{A}$ to binary relations over the nodes of the networks occurring in the play, defined by $h(a) = \{(x, y) : N_i(x, y) \leq a \text{ for some } i < \omega\}$, for any $a \in \mathcal{A}$. Because all network defects were eliminated during the game, h yields a representation of $\mathcal{A}$. (There are some minor technical complications here, and we refer the interested reader to [HH97b, HH97a].) In fact, by a compactness argument, a winning strategy for $\exists$ implies representability for arbitrary (even uncountable) relation algebras.

We can define a sequence of approximations to representability by asking if $\exists$ has a winning strategy in the game, $G_n(\mathcal{A})$, which is like $G_\omega(\mathcal{A})$ but curtailed after n rounds ($n < \omega$). By a König tree lemma argument, a winning strategy for her in each of these curtailed games gives a winning strategy for her in the full, infinite length game. To see this, suppose $\exists$ has a winning strategy in each of the games $G_n(\mathcal{A})$, for $n < \omega$. In a play of $G_\omega(\mathcal{A})$ let her adopt the following strategy. In round t let $\forall$ pick the edge (x, y) from N_{t-1} and elements $r, s \in \mathcal{A}$. Inductively, suppose that infinitely many of her strategies for the finite length games have been used in her choice of moves so far and they are still running. By assumption this is true initially. Each of these strategies will tell her either to reject or accept $\forall$'s move.[1] If infinitely many of the strategies tell her to reject, then she rejects in the infinite length game. Otherwise, infinitely many finite game strategies tell her to accept, which she does in the infinite length game. As we move to the next round, her strategy for the finite length game $G_t(\mathcal{A})$ will 'run out', but all her other strategies that are running are still running in the next round. Thus we re-establish the induction hypothesis: she is in a situation where infinitely many strategies have been followed and are still running. Thus she can continue in this way forever and win the play.

To obtain a recursive axiomatisation, it remains to find a formula saying that $\exists$ has a winning strategy in the game of length n. This is not hard to do. *Very roughly,* ϕ_n^0 is a formula that says "the current graph is a network with no more than n nodes" and ϕ_n^{m+1} says "for any possible $\forall$-move, either ϕ_{n+1}^m holds on the graph obtained by rejecting or ϕ_{n+1}^m holds on the graph obtained by accepting his move". Thus, ϕ_2^m holds of a network N of size ≤ 2 iff $\exists$ has a winning strategy in $G_n(\mathcal{A})$ where play starts with N. It is now easy to turn the ϕ_2^m ($m < \omega$) into sentences axiomatising the representable relation algebras.

Games can also be used to reprove Monk's non-finite axiomatisability result, by constructing a sequence of algebras $\mathcal{A}_n$ such that $\exists$ has a winning strategy in $G_n(\mathcal{A}_n)$ (for each $n < \omega$), but no winning strategy in $G_\omega(\mathcal{A}_n)$. Game-theoretic arguments then show that $\exists$ has a winning strategy in $G_\omega(\mathcal{B})$ where $\mathcal{B}$ is any non-principal ultraproduct of the $\mathcal{A}_n$. Non-finite axiomatisability follows from this, using Lós theorem. This theorem states that if any first-order formula σ is true in $\mathcal{B}$ then is is true in 'many' of the $\mathcal{A}_n$. Now if the representable relation algebras could be axiomatised by a finite set of formulas, it could be axiomatised by a single formula σ (just take the conjunction of the finite set of formulas). But then, since $\mathcal{B}$ is representable, σ must be true in $\mathcal{B}$. By Lós theorem, σ must be true in many of the $\mathcal{A}_n$. But *none* of the $\mathcal{A}_n$ are representable, so σ is true in none of them, which

[1] It is crucial for this argument that $\exists$ has only a finite number of choices, in fact just two choices, for her move. There are other games that we may consider where this is not so, and then it may be possible to find relation algebras where $\exists$ has a winning strategy for all finite length games but not for the ω length game. We will return to this point later.

is a contradiction.

Game-theoretic techniques can also be used to show that the class of 'completely representable' relation algebras is not elementary (it cannot be defined by *any* set of first-order formulas). A complete representation of a relation algebra $\mathcal{A}$ is a representation in which arbitrary disjunctions (and conjunctions) are preserved, wherever they are defined. So for any set $S \subseteq \mathcal{A}$ with a least upper bound ΣS in $\mathcal{A}$, a complete representation h satisfies $h(\Sigma S) = \bigcup\{h(s) : s \in S\}$. A completely representable relation algebra must be atomic.

To deal with complete representations, we define another game, $H_\omega(\mathcal{A})$. This game is similar to $G_\omega(\mathcal{A})$, except that we use graphs in which the edges are labelled by atoms of $\mathcal{A}$. One complication for $\exists$ is that she cannot 'accept' in the way she did before by leaving many of the new edges labelled by the top element 1; she must actually choose atoms to label all the edges. Thus, she may have infinitely many choices in each round. It can be shown, using similar arguments to those above, that for a countable relation algebra $\mathcal{A}$, a winning strategy for $\exists$ in $H_\omega(\mathcal{A})$ is equivalent to the existence of a complete representation of $\mathcal{A}$. To show that the class of completely representable relation algebras is not elementary, we construct a countable relation algebra $\mathcal{A}$ such that $\exists$ has a winning strategy in the finite length game $H_n(\mathcal{A})$ for each $n < \omega$, but not in $H_\omega(\mathcal{A})$. Though $\mathcal{A}$ is not completely representable, it turns out that $\exists$ has a winning strategy in $H_\omega(\mathcal{B})$, where $\mathcal{B}$ is a non-principal ultrapower of $\mathcal{A}$. Although $\mathcal{B}$ may be uncountable, we can find a countable elementary subalgebra $\mathcal{C}$ of $\mathcal{B}$ in which $\exists$ still has a winning strategy. So $\mathcal{C}$ is completely representable, but elementarily equivalent to $\mathcal{A}$ which is not completely representable. Thus, the class of completely representable relation algebras is not closed under elementary equivalence, and cannot form an elementary class.

Other games have been devised to show that the atom structure of an atomic relation algebra does not determine its representability; that it is undecidable whether a finite relation algebra is representable; and to give non-finite axiomatisability results for such classes as the relational reducts of n-dimensional cylindric algebras, etc. Not all these results are negative, though: we have already seen how games can be used to derive a recursive axiomatisation of the representable relation algebras.

The work in algebraic logic ties in with work in other fields. Here in Amsterdam, van Benthem, Venema, Marx, de Rijke and others developed arrow logic in part as a link from relation algebra to modal logic. The Budapest algebraic logic group has explored many aspects including the link between algebra and logic, decidability and complexity results for various algebraic logics, and they have considered the whole 'finitization problem' in depth. Maddux, in the US, has developed the field significantly and has explored relativized representations among many other things; his and Lyndon's work is in many ways a foundation for the game-theoretic results sketched here. There are numerous applications in planning and temporal reasoning. Many other groups, in the US, South Africa, New Zealand and so on, are working in this field, but we cannot summarise the field here.

The game-theoretic approach appears to have a number of advantages. One of them is that it is very natural to define a sequence of approximations to a property characterised by an infinite length game. These approximations are obtained by considering finite length games that are curtailed after n rounds. Often these approximations characterise classes of interest in their own right, and they can be useful for proving (e.g.) non-finite axiomatisability results.

Another advantage is that it makes the proofs more intuitive. For example, there are other axiomatisations of the representable relation algebras, but they really are very difficult to comprehend. With games, the axioms say "$\exists$ has a winning strategy in the game of length n", so the meaning is clear. In many of the games we construct, the second player $\exists$ is effectively trying to build a representation or prove the theorem, so her strategy corresponds to the proof.

Future developments based on this approach might involve work on finite representations — where we want a representation with a finite domain. Another line of enquiry is to ask for which values of n does a winning strategy in the game of length n ensure a winning strategy in the ω-length game. This might be used to obtain tighter complexity results. Designing algebraic logics to model various systems, such as interactive systems, is a field that is currently being investigated. Indeed, games have already been used to model interactive systems, and we believe that they could provide a useful tool for more sophisticated modelling.

References

[Boo51] G Boole. *The mathematical analysis of logic, being an essay towards a calculus of deductive reasoning.* Oxford, Basil Blackwell, 1951. Original work published in 1847 in Cambridge by MacMillan, Barclay and MacMillan and in London by George Bell.

[DeM60] A De Morgan. On the syllogism, no. iv, and on the logic of relations. *Trans. Cambr. Philos. Soc.*, 10:331–358, 1860. Republished in Rare masterpieces of philosophy and science. Routledge & Kegan Paul, 1966.

[HMT] L Henkin, J D Monk, and A Tarski. *Cylindric Algebras Part I.* North-Holland, 1971. *Part II.* North-Holland, 1985.

[HH97a] R Hirsch and I Hodkinson. Axiomatising various classes of relation and cylindric algebras. *Logic Journal of the IGPL*, 5(2):209–229, 1997.

[HH97b] R Hirsch and I Hodkinson. Step by step — building representations in algebraic logic. *Journal of Symbolic Logic*, 62:225–279, 1997.

[JT48] B Jónsson and A Tarski. Representation problems for relation algebras. *Bulletin of the American Mathematical Society*, 54, 1948.

[JT51] B Jónsson and A Tarski. Boolean algebras with operators, I. *American Journal of Mathematics*, 73:891–939, 1951.

[JT52] B Jónsson and A Tarski. Boolean algebras with operators, II. *American Journal of Mathematics*, 74:127 - 162, 1952.

[Kan72] I Kant. *Introduction to logic.* Westport, Conn.: Greenwood Press, 1972.

[Lyn50] R Lyndon. The representation of relational algebras. *Annals of Mathematics*, 51(3):707–729, 1950.

[Mon64] J D Monk. On representable relation algebras. *Michigan Mathematics Journal*, 11:207–210, 1964.

Games in logic

Wilfrid Hodges
Queen Mary and Westfield College, University of London

1 A question

It seems that the first logician to present his work as a game was the renaissance scholar Agostino Nifo, who in 1520 published a textbook called 'Logic as a game' (in Latin: 'Dialectica ludicra'). As far as I know, it has never been reprinted, and I have yet to see a copy. Game-theoretic ideas began to reappear in logic around the beginning of this century (apologies! the twentieth century), and since the mid century there has been an explosion of examples.

Why? What is it about games that makes them an appealing format for logical systems? Why do people regard a game-theoretic version of a logical idea as a helpful thing to have? I used to think that the answer was obvious: games involve competition, death and victory, deception and frustration—exactly what one expects from a good television thriller. Sadder and wiser, I now realise not only that the facts don't support this easy analysis, but also that the question really does matter. Just within this conference we are hearing Abramsky, Krabbe, Sandu and others offering games as in some sense an *explanation* of concepts from logic, language or computation. In what sense, and how do games provide an explanation in this sense?

Actually there are two kinds of answer, which I shall call the motivational and the mathematical. In the rest of this abstract, let me make a start at the motivational first, then the mathematical.

2 A motivational answer

Sometime in the 1930s, Wittgenstein introduced the idea of games as a paradigm of language. To the best of my knowledge, nobody ever wins or loses a Wittgenstein language game. When Wittgenstein speaks of a 'game', he seems to mean 'activity carried out according to rules which are accepted by the participants'. In 1928 Hilbert described his own approach to the foundations of mathematics in terms of games, and again he meant rule-governed activities. (Brouwer had accused him of playing games; Brouwer meant it as an insult, but Hilbert took it as a compliment. I guess that for Brouwer, 'game' meant 'waste of time'.)

Recently Hyland coined the phrase 'games for fun' to mean games which are played by certain rules, but without any notion of winning, losing or payoff. The Hyland-Ong game semantics for PCF consists of games for fun. Most of the games that one meets in logic are not games for fun. At least one of the players is trying to achieve something, and she loses the game if she fails to achieve it. Let me pick out two of the main paradigms on offer.

The first paradigm is the gladiatorial contest. Each player is out to defeat the other player—for example by reducing him or her to contradiction, which is death for a logician. This is a symmetrical situation, and one expects that the rules governing the moves of the two players should be more or less the same. (Not entirely the same, because one player has to start.) In many games of this general type, some possible moves are labelled Attack, and the other player is allowed certain replies by way of Defence.

No doubt there are such games. But I don't think I have met a convincing example in logic yet. One common sign that something has gone wrong is that the rules for the two players are asymmetrical in ways which are not explained by the alleged aim. For example in Lorenzen's dialectical games, one player is not allowed to propose an atomic sentence unless it has already been proposed by the other player. From the gladiatorial point of view, this asymmetry is a complete mystery.

Another difficulty is that often the moves which are alleged to be Attacks are hard to construe as attacks. Sticking with Lorenzen's games as they are usually interpreted, take this example:

> Player A states 'If P then Q'.
> Then player B attacks by stating 'P'.

Whyever should this reply be construed as an attack? Take this example from real life:

> Person A says 'I'm not sure I can get to Julie's party this evening. There's an examiners' meeting this afternoon, and if there are going to be a lot of difficult cases then I shall have to stay late.'
> Person B replies 'There are going to be a lot of difficult cases'.

Socially speaking, this reply of B looks to me much more like a support than an attack. Probably A is trying to get out of attending the party, and B is aiding his alibi. Of course one can rig up examples where B's reply could be seen as an attack on A's position. But they have to be manufactured for the purpose; B's reply is not an attack by virtue of the logical forms of the sentences involved. This seems to me very damaging to the claim that Lorenzen's games, thus interpreted, give a foundation for logic—the proposed foundation relies on being careless about motivation.

A second common paradigm is that of solving a problem. We suppose that the second player, let me call her ∃loise, has to solve a problem. During the game she aims to reduce the problem progressively to problems that she can solve outright. For example, suppose the problem P is one that she can solve by either solving problem Q or solving problem R. Then she can choose one of Q and R, and this will be her next move in the game. Alternatively the problem P may be one that she can solve by solving both Q and R. In that case, so the explanation goes, she needs to be able to solve both, so the choice of which one to go to can't be left to her. Hence we let the other player, call him ∀belard, move by deciding whether the next problem is Q or R. We reckon that ∃loise wins if the game eventually reduces the problem to one that she can solve outright, and ∀belard wins otherwise.

Here the asymmetry is quite public. Semantics for logical languages are often presented in these terms. Thus ∃loise verifies (Q or R) by either verifying Q or verifying R, and she verifies $\exists x P(x)$ by verifying $P(a)$ for some a. Dually, ∃loise verifies (Q and R) by verifying both Q and R, and she verifies $\forall x P(x)$ by verifying $P(a)$ for all a. In the dual cases, ∀belard makes the choices.

The difficulty here is that it is completely unclear what ∃loise has achieved by winning the game. Suppose the problem was (Q and R), ∀belard chooses Q and ∃loise solves or verifies Q outright. Has she solved the original problem? No. Then what has she done? At this point one comments that the important question is not whether ∃loise wins this play or that, but whether she has a winning strategy. This comment is absolutely correct, but it's also a giveaway. What is the strategy supposed to be a strategy *for*? And if we don't know what ∃loise is trying to achieve when she plays the game, what has been explained by introducing the notion of a game in the first place?

I think there is a better paradigm for both the Lorenzen and the semantic games, and that is the paradigm of an examination. ∀belard is the examiner, ∃loise is the student. ∃loise is being examined in whether she knows how to do something. If that thing, P, is done by doing either Q or R, then it is natural for the examiner to invite her to take her pick. (If he insisted on Q, she could fairly answer that she can do P but not that way.) If it is done by doing both Q and R, then the examiner can fairly choose which of them to test her on. ∃loise's motivation is to pass a test of knowledge; she wins if she has correct answers to all the questions put to her. A winning strategy is what she has if she can pass the test regardless of what questions are put to her.

What is the motivation of ∀belard? That's neither here nor there. He may be the vicious sort of examiner who wants to catch her out. On the other hand he may be so sure of her ability that he wants to demonstrate her skills by giving her hard problems that he knows she can solve (like Leopold Mozart showing off his son and daughter to the crowned heads of Europe). He may not care one way or the other (like a driving test examiner—he gets paid anyway).

Or he may be a teacher who is training ∃loise by taking the component problems in a certain order. This rings a bell. The Abbreviatio Montana, an anonymous early medieval textbook of debates, begins by distinguishing the two participants in a debate and saying what their 'purposes' are. The purpose of one debater is 'to prove on the basis of readily believable arguments a question that has been proposed'. The purpose of the other debater is 'to teach the art'. I would value a recasting of Lorenzen's dialogue games from this point of view, not least because it seems closer to Lorenzen's own perspective than the usual gladiatorial view.

Certainly not all logical games fit the exam paradigm. For example logical games of imperfect information, like Abramsky's and some mentioned by Sandu, are hard to squeeze into this framework. I hope that by the end of this conference I shall have a better understanding of what the players in these games are trying to achieve. The games of Hirsch are best seen as cooperative games where two players (in fact countably many, but each player considers all the other players as a single opponent) are each doing their own thing; the whole point is that one player's thing doesn't prevent another player's thing, though it may affect how the other player achieves it.

3 A mathematical answer

There is no one right answer to the motivational question, but there are some answers that cover a useful range of cases. Mathematically the same is true. In the short abstract I noted three groups of logical games: (1) semantic games, which include quantifier games and the Barwise-Etchemendy teaching game 'Tarski's world'; (2) comparison games such as back-and-forth and bisimulation; (3) cut-and-choose games, including various model-theoretic rank operations and Vapnik-Chervonenkis dimension from learning theory.

All these games are closed in the sense of Gale and Stewart. This means (adapting the definitions of Gale and Stewart to the usual situation in logical games) that (a) every play is a win either for ∀belard or for ∃loise, and (b) ∀belard never wins a play unless he has already won after some finite number of moves. Another way of saying (b) is that ∃loise wins provided she manages to stay alive through every finite stage of the game. Gale and Stewart proved that in every such game (of perfect information), one of the players has a winning strategy. This extends the theorem of Zermelo (1912), which says the same for every game in which one player or the other wins after a finite number of steps.

One major reason for the interest in these games is that they all carry a natural notion of rank on the possible positions in a play. The first person to realise this was Fraïssé, who worked out the details for finite rank and back-and-forth games in the mid 1950s (though he never used the language of games in this context—we owe that to Ehrenfeucht). I think it is folklore among descriptive set theorists that Fraïssé's rank, properly generalised, is essentially the same thing as the Lusin-Sierpiński ordering which one can read about in Kuratowski's textbook of topology. The work of Moschovakis on inductive definitions contains a translation of a kind between the games and the ordering; I am not sure how general it is (though I hope to know by the time of this conference). The direct definition of the ranks of positions is something I extracted from a lecture by Hajnal in 1980 on some difficult work of Shelah in cardinal arithmetic. I learned later that Mathias had come on this definition of ranks independently.

The idea is to measure how close ∃loise is to being in winning position. The position has rank infinity if it is winning for ∃loise, and it has rank -1 if ∃loise has already lost the game by this stage. In any other case the rank is an ordinal number, and the higher the ordinal, the better for ∃loise. The rank is defined by induction on ordinals, and the crucial clause of the definition is as follows. Let $\bar{a}$ be a position and i an ordinal. Then $\bar{a}$ has rank at least $i+1$ if one of the following holds:

> either ∃loise has the next move, and for at least one possible choice b, $\bar{a}b$ is a position of rank at least i;

or ∀belard has the next move, and if b is any of his possible choices, then $\bar{a}b$ is a position of rank at least i.

There is a routine clause to cover limit ordinals.

The case that Fraïssé discussed is as follows. Two structures A and B are given; ∃loise is trying to prove that the structures are indistinguishable. (Either ∀belard is trying to prove the contrary, if we want to be gladiatorial; or he is just testing ∃loise if we prefer the exam paradigm. It makes little difference here.) ∀belard and ∃loise take turns to choose elements of the structures; in each pair of moves, ∀belard chooses an element from either A or B, and ∃loise replies by choosing an element of the other structure. ∃loise loses if the elements chosen so far from one structure satisfy different atomic formulas from those chosen so far from the other, regardless of which player chose which elements. This defines a game $EF(A, B)$ (where EF is for Ehrenfeucht and Fraïssé).

We get Fraïssé's rank if we make a slight adjustment in the definition of rank above, by grouping each pair of successive moves of ∀belard and ∃loise as a single step, and assigning ranks only at the ends of steps. Fraïssé showed that under some reasonable assumptions on the language, if n is any natural number, then the opening position in $EF(A, B)$ has rank at least n if and only if A and B agree on all sentences of complexity at most n (I have left out the definition of complexity). Carol Karp showed how to extend the language so that the same holds for all ordinal ranks. Today we have various adaptations of this machinery, which are used to measure the similarity between databases and the expressive power of database query languages. The back-and-forth idea also adapts directly to comparison of processes by bisimulation; the ranks are still there, but I don't think they have been so thoroughly exploited in this context.

Then come the semantic games. In these we have a structure A and a sentence ϕ. ∃loise is trying to show that ϕ is true in A; or if you prefer the exam paradigm, she is being examined on her ability to show that ϕ is true in A. The information given us by the rank function is a little mysterious in this case. It measures in some sense how close a false sentence is to being true. Geach says somewhere that there are no degrees of truth, though there are little lies and big lies; if you like to look at it this way, the ordinal rank is lower in proportion as the lie is bigger.

Seen as examinations, the semantic games generally have one unexpected feature: ∃loise's answers are cumulative, so that her response to a later question has to be read as including her earlier responses. (She chooses elements, and the state of play depends on all the elements chosen so far.) Of course one can set exams this way if one wishes to. In the Hintikka-Sandu variant, the games are of imperfect information, so that ∃loise is expected to answer without being allowed to remember all the previous questions and answers, even though they may be relevant. Motivationally I find this a difficult idea; can we explain what it is that ∃loise is being examined in? In particular can we explain it non-trivially, i.e. without simply describing the game itself? The general philosophy of section 2 above was that a game has explanatory value in proportion as we can give a convincing motivation to at least one of the players. I am not sure that the Hintikka-Sandu games meet this test convincingly; they might in fact have less explanatory value than other forms of semantics for the Hintikka-Sandu languages.

Finally we come to the cut-and-choose games. These were introduced into logic by Morley in 1965 and into learning theory by Vapnik and Chervonenkis in 1971. The basic idea in both cases was the same: to measure the amount of information needed to identify the points in a certain space. Morley's games were of perfect information, and those of Vapnik and Chervonenkis (on the analysis that I have in mind) were not; but in context this turns out not to be a major difference. These games are stomping-grounds for some very beautiful theorems on families of sets, and they form an excellent introduction to this area of combinatorics.

4 An analogy?

In one of his books on the foundations of the theory of evolution ('The extended phenotype', Oxford University Press 1982, p. 81), Richard Dawkins has a passage that caught my eye:

> The whole purpose of our search for a 'unit of selection' is to discover a suitable actor to play the leading role in our metaphors of purpose. We look at an adaptation and want to say, 'It is for the good of ...'. Our quest in this chapter is for the right way to complete that sentence.

Yes, that's exactly right for us too. Games are a metaphor of purpose; to use them as a solid foundation we need to spell out the purpose. This is not as wild an analogy as it might seem. If one applies Dawkins' question (as Dawkins himself certainly would) to the evolutionary games of Maynard-Smith, then one sees that Dawkins' question and ours are the same, and the reason for them is the same too.

Lorenzen Dialogue Games: An Approach to Interpersonal Reasoning

Extended Abstract

Erik C.W. Krabbe

1 Introduction

The theory of Lorenzen dialogue games (dialogical logic) characterizes logical constants by their use in a critical dialogue between two parties: a Proponent, who has asserted a thesis and an Opponent who challenges it.

For each logical constant, a rule specifies how to challenge a statement that displays the corresponding logical form, and how to respond to such a challenge. These rules are incorporated into systems of regimented dialogue that are games in the game-theoretical sense. Dialogical concepts of logical consequence can then be based upon the concept of a winning strategy in a (formal) dialogue game: ψ is a logical consequence of $\varphi_1,...,\varphi_n$ if and only if there is a winning strategy for the Proponent of ψ *vis-à-vis* any Opponent who is willing to concede $\varphi_1,...,\varphi_n$. But it should be stressed that there are several plausible (and nonequivalent) ways to draw up the rules.

After a brief sketch of the main characteristics of the dialogical framework (Section 2), one way to draw up the rules will be expounded in Section 3. In Section 4 it is shown how quick proofs of completeness may be obtained. Section 5 adds some material on motivations for and applications of the dialogical approach to logic.

2 Main characteristics

Logic is to provide us with viable concepts of logical consequence, logical truth, consistency and so on, and for that end to elucidate the meaning of logical constants. Dialogical logic, which is the logical part of dialogue theory, goes about this by assigning to each logical constant a clear 'meaning-in-use', where the context of use is one of critical dialogue arising from a conflict of opinions about a statement: the initial thesis. This thesis – the question at issue one might say – is challenged by the Opponent (**O**) and defended by the Proponent (**P**). The Opponent may or may not have granted some statements in advance: the initial concessions or hypotheses of the dialogue. The dialogical approach is to be compared to, and contrasted with, on the one hand semantic or model-theoretic characterizations of the logical constants and, on the other hand deduction-theoretic characterizations.

Each logical constant is characterized by the specific modes of challenge of which the participants may avail themselves to attack or question a statement with that particular logical constant as its principal operator; as well as by the specific responses to these challenges. For instance, a conjunctive statement $\varphi\wedge\psi$ can be challenged in two ways: by questioning φ and by questioning ψ. The response to the first type of challenge consists of φ, whereas the response to the second type of challenge consists of ψ. In the case of a disjunctive statement $\varphi\vee\psi$, however, the only type of challenge pertains to this statement in its totality, but the responses are the same, with the distinctive difference that in this case the choice between φ and ψ is the respondent's, rather than the challenger's. A survey of these so-called *logical rules* is given below.

The logical rules are not sufficient, for the meaning of each logical constant also depends on global characteristics of the dialogues. *Structural rules* stipulate who may challenge what and how often, whether responses may be repeated, and so on. Finally, *rules for winning and losing* determine the situations in which a participant may be declared to be the winner (or loser) of the dialogue. A full set of rules of all three types (see the table and the list of rules below) defines a *dialogue game*, or *dialectic system*.

If a dialogue game makes use of an interpreted nonlogical vocabulary, the game and its dialogues are called *material;* otherwise they are called *formal.* In material games, typically, elementary statements can be defended by pointing out their (extra-dialogical) truth. Thus observation and other ways of fact finding are connected with material dialogues. In formal dialogue games these material modes of defense are not available.

3 An example

The following formal dialogue game yields intuitionistic (constructive, effective) predicate logic. It is based on a first order language for predicate logic with an infinity of individual constants: *a*, *b*,... Formulas are denoted as φ, ψ,... The result of substituting an individual constant *a* for the free variable *x* in the formula φ is denoted as $\varphi[a/x]$.

This game is asymmetric in the following sense: at all times **P** has a statement to defend, whereas **O** never has a thesis to defend. However, **P** must have some means to exploit the concessions. To that end **P** is allowed to question the concessions in order to generate more detailed concessions. The corresponding moves of question (by **P**) and answer (by **O**) are formally identical to the moves of challenge (properly so called) by **O** and response (or, defense) by **P**, but the intuitive motivation is different. Thus the asymmetry of the game remains hidden as far as the logical rules are concerned. It is clearly born out, however, by the structural rules and by the very different ways **P** and **O** can win a dialogue.

Table of Logical rules:

	Statement	*Challenge/question*	*Defense/answer*
$Rule_{\to}$	$\varphi\to\psi$	*(?)* φ	ψ
$Rule_{\neg}$	$\neg\varphi$	*(?)* φ	⊥ (an elementary statement of absurdity)
$Rule_{\vee}$	$\varphi\vee\psi$	*?*	φ / ψ (defendant / answerer chooses)
$Rule_{\wedge}$	$\varphi\wedge\psi$	*L?* / *R?* (challenger / questioner chooses)	φ / ψ
$Rule_{\forall}$	$\forall x\, \varphi$	*a?* (challenger / questioner selects a constant)	$\varphi[a/x]$
$Rule_{\exists}$	$\exists x\, \varphi$	*?*	$\varphi[a/x]$ (defendant / answerer selects a constant)
$Rule_{El}$	elementary statement	*?*	none

Structural rules

1. There are two participants: the Proponent **P**, who defends a thesis, and the Opponent **O**, who may or may not have granted a number of concessions.
2. The participants move alternately. **O** makes the first move: a challenge of the thesis.
3. Each move by **O** is either a challenge or an answer according to a logical rule.
4. Each move by **P** is a question or a defense according to a logical rule or a winning remark, that is either *Ipse dixisti!* (You said so yourself!) or *Absurdum dixisti!* (You said something absurd!).
5. **P** is not allowed to question **O**'s elementary statements.
6. A winning remark *Ipse dixisti!* is allowed only if the most recently challenged statement of **P**'s can also be found among **O**'s concessions.
7. A winning remark *Absurdum dixisti!* is allowed only if $\perp$ can be found among **O**'s concessions.
8. The only statement **P** is allowed to defend is the one that was most recently attacked by **O**.
9. Except for the initial challenge, each move by **O** is to consist of a reaction on the immediately preceding move by **P** (answering **P**'s question, or challenging a newly introduced statement).
10. Before the onset of the dialogue proper, **P** is to announce a limit on the number of **P**-moves (a natural number). **P** is not allowed any moves beyond that number.

Rules for Winning and Losing

11. **P** wins by making a winning remark.
12. **O** wins whenever it is **P**'s turn to make a move, whereas no legal move is available for **P**.

The following dialogue accords strictly with the rules of this constructive dialectic system:

Initial position:

	c1:	$\forall x(Px \rightarrow Qx)$	(a concession)
	c2:	$\exists xPx$	(a concession)
	t:	$\exists xQx$	(the thesis)
	P:	100	(**P** sets a limit, see Rule 10)
1	**O**:	*?*	(**O** challenges the thesis)
2	**P**:	*?*	(**P** questions c2)
3	**O**:	P*a*	(**O** answers the question)
4	**P**:	Q*a*	(**P** responds to the challenge)
5	**O**:	*?*	(**O** challenges 4)
6	**P**:	*a?*	(**P** questions c1)
7	**O**:	P*a*$\rightarrow$ Q*a*	(**O** answers the question)
8	**P**:	*(?)* P*a*	(**P** questions 7: do you want to challenge P*a* or to concede Q*a*?)
9	**O**:	Q*a*	(**O** concedes)
10	**P**:	*Ipse dixisti!*	(**P** wins, see Rules 6 and 11)

4 Completeness

The dialectic system presented above can be shown to be both correct and complete when compared to proof-theoretic (or model-theoretic) versions of intuitionist predicate logic; that is, whenever the game admits of a winning strategy for **P**, where **P** defends ψ and **O** concedes $\varphi_1,...,\varphi_n$ (notation: $\varphi_1,...,\varphi_n\mathbf{W}\psi$), ψ is intuitionistically provable from $\varphi_1,...,\varphi_n$ as premises (notation: $\varphi_1,...,\varphi_n.^{i}\psi$), and vica versa.

One way to go about this is to represent positions in dialogue (up to equivalence) by dialogue sequents that depict precisely those features of a position that are relevant to the study of strategy. A dialogue sequent may be defined as a sextuple:

$$\Pi; \Delta / T /_{\mathbf{N}} Z; \Gamma$$

where Π = the set of **O**'s concessions that **P** may question; Δ = the set of answers from which **O** may select one for the next move (which has to be **O**'s); T= the local thesis, i.e., the sentence last challenged by **O** (to be omitted if a fresh challenge is sure to take place in the next move); **N** = the party that is to make the next move (**O** or **P**); Z = the sentence **O** may challenge in the next move (which has to be **O**'s), if any; Γ = the set of defenses from which **P** may select one.

Positions in which **P** can make a winning remark are all depicted by sequents of the following two types (empty elements of the sextuple are simply omitted; '$\Pi \cup \{\varphi\}$' is written as 'Π,φ'):

$$\Pi,\varphi \ /\varphi /_{\mathbf{P}} \Gamma \quad \text{and} \quad \Pi,\bot / \varphi /_{\mathbf{P}} \Gamma$$

A strategy for P can now be codified as a labeled tree, $< T , f >$, where T is a tree and f a function which assigns dialogue sequents to the nodes of the tree. The sequent that represents the initial position is to be assigned to the root of the tree (**N** = **O**). Along each branch sequents with **N** = **O** and with **N** = **P** alternate and the succesion is to be such that the branch depicts a possible dialogue. Branchings occur only beneath those nodes where **N** = **O** and represent every option available to **O** in the position depicted by the sequent assigned to that node. Such a labeled tree will be called a **P**-*strategy diagram.* A **P**-*winning strategy diagram* is a **P**-strategy diagram such that each branch is finite, and such that the sequents asssigned to the final nodes of the tree all depict situations in which **P** can make a winning remark.

It can be shown that the construction of a P-winning strategy diagram is governed by a limited number of reduction rules, much like the reduction rules in semantic (or deductive) Beth-tableaux. (In fact, the so-called dialogical tableaux are very similar to Beth-tableaux and P-winning strategy diagrams may be identified with closed dialogical tableaux.) As an example of such a simple reduction rule, consider (elements of Γ or Δ are put in brackets):

Rule OI$\rightarrow$ $$\Pi /_{\mathbf{O}} \varphi\rightarrow\psi \ \Rightarrow \ \Pi,\varphi / \varphi\rightarrow\psi /_{\mathbf{P}} [\psi]$$

This rule means that any node labeled with a sequent as depicted on the left is to have exactly one successor and that to this successor the corresponding sequent on the right is to be assigned. In terms of dialogue: in a situation as depicted on the left **O** has no choice but to challenge $\varphi\rightarrow\psi$. This is a so-called compulsory rule. Some other rules are 'choice rules', for instance:

Rule P$\rightarrow$ $$\Pi,\varphi\rightarrow\psi / \chi \ /_{\mathbf{P}} \Gamma \ \Rightarrow \ \Pi,\varphi\rightarrow\psi; [\psi] / \chi /_{\mathbf{P}} \varphi; \Gamma$$

This rule presents the option to introduce a node labeled with a sequent as appears on the right as a successor to any node with the corresponding sequent on the left. But this is optional. Perhaps no successor is needed: the sequent on the left might depict a situation in which a winning remark can be made. Also their may be other choice rules that apply. In terms of dialogue: one option for **P** is to question $\varphi\rightarrow\psi$, but there may be other options.

Now, to show correctness, it suffices to define a suitable mapping Φ from dialogue sequents to deductive sequents ($\varphi_1,...,\varphi_n / \psi$) so that for an initial position $\varphi_1,...,\varphi_n /_{\mathbf{O}} \psi$ one gets $\Phi(\varphi_1,...,\varphi_n /_{\mathbf{O}} \psi) = \varphi_1,...,\varphi_n / \psi$ and such that it can be proved by induction that all the images of sequents that appear in a **P**-winning strategy diagram are intuitionistically valid. The other way around is to be proved by a straightforward induction on deductive Beth tableaux. For details see (Krabbe, 1985).

5 Motivations and applications

The connection between dialogues and logic, which goes back to Aristotle's *Topics*, was reintroduced by Paul Lorenzen in 1958 (see Lorenzen and Lorenz 1978). Originally, the motivation was to be found in the philosophy of mathematics: the dialogues were to yield a criterion of constructivity and to justify a constructive logic without recourse to Brouwerian solipsism. But studies by Kuno Lorenz and others were not slow to point out that with a little fiddling of the structural rules the dialogue games could be forced to yield classical logic instead, although constructive logic seemed more 'natural' from the dialogical point of view.

In the meantime it had become clear how logical concepts were to be defined dialogically. We have seen above how a definition of logical consequence can be framed in terms of the existence of a winning strategy for the Proponent in a formal game. The case of an empty set of concessions gives us a definition of logical truth. Consistency of a set of statements can be defined as the existence of a winning strategy for an Opponent who concedes these statements *vis-à-vis* a Proponent who defends $\perp$. This strategy shows how **O** can maintain this position without conceding absurdity. Clearly, different formal dialogue games may give rise to different concepts of logical consequence, to different logics, one might say.

The challenges and responses given in the logical rules of dialogical logic are closely similar and often identical to those given in Hintikka's rules for game-theoretic semantics. But in game-theoretic semantics one tries to exploit the concept of a game to construct a semantic theory (for natural language), whereas dialogical logic is rather to be conceived as providing an alternative to the semantic approach. Even so, the two approaches are closely related.

Later on dialogical logic came to be part of a program for a normative reconstruction of the language of science, ethics, philosophy and politics that was worked out by Paul Lorenzen and others in the so-called Erlangen school of German constructivism (see Lorenzen and Schwemmer 1973 and Lorenzen 1986). The dialogue rules contribute to this program by giving us reconstructed versions of the logical constants.

More generally, dialogical logic has been influential in the development of argumentation theory, including the theory of argumentative discussions and fallacy theory (see Van Eemeren, Grootendorst, Snoeck Henkemans et al. 1996). A recent monograph by Walton and Krabbe (1995) contains a formal model of critical discussion in which a Lorenzen type of dialectic is embedded as a more rigorous way of arguing into a more permissive Hamblin-styled type (Hamblin 1970). This system meets the condition that though generally commitments can be retracted, not anything goes. Commitments that result from arguing things through in Lorenzen-styled parts of dialogues are not so easy to retract.

Recent dissertations in logic, defeasible reasoning and linguistics witness of a small but continuing stream of interest in the dialogical approach: Valerius (1990) (on structural rules and rules of winning and losing), Vreeswijk (1993) (on defeasible reasoning) Van Hoof (1995) (on conditionals), Fach (1996) (on the interaction between man and computer), Machate (1996) (on stress rules) Starmans (1996) (on argument based reasoning), and Strobel (1997) (on telephone answerers).

References and further reading

Barth, Else M. and Erik C.W. Krabbe (1982) *From Axiom to Dialogue. A Philosophical Study of Logics and Argumentation,* Berlin and New York: Walter de Gruyter. (Chs 3 and 4 provide normative foundations, from the point of view of a theory of argumentative discussions, for a number of dialectic systems. Chs 5, 7 and 11 discuss the metatheory of dialectic systems and present proofs of equivalence with model-theoretic and deduction-theoretic systems.)

Fach, Peter W. (1997), *Dialogspiele in der Mensch-Computer Interaktion: Eine Fallstudie am Beispiel von Online-Hilfen,* Münster, etc.: Waxmann (dissertation, Stuttgart University).

Felscher, Walter (1986) 'Dialogues as a Foundation for Intuitionistic Logic'. In: D. Gabbay and F. Guenthner, *Handbook of Philosophical Logic III: Alternatives to Classical Logic,* Dordrecht, etc.: Reidel, pp. 341-72. (A useful and concise introduction to the subject, with a useful bibliography. A bit technical.)

Haas, Gerrit (1984) *Konstruktive Einführung in die formale Logik,* Mannheim, etc.: Bibliographisches Institut, Wissenschaftsverlag. (This is both an introduction to logic and an introduction to dialogical logic, with many examples, detailed explanations and proofs.)

Hamblin, Charles L. (1970), *Fallacies,* London: Methuen. Reprinted in 1986, Newport News, VA: Vale Press.

Krabbe, Erik C.W. (1985) 'Formal Systems of Dialogue Rules', *Synthese 63 (3):* 295-328. (Includes a survey of options in constructing a dialectic system, with a closer study of constructive systems and equivalence proofs. Only the last part is highly technical. Useful bibliography.)

Lorenzen, Paul (1969) *Normative Logic and Ethics,* Mannheim, etc.: Bibliographisches Institut. (An early and brief exposition in English.)

Lorenzen, Paul (1986) *Lehrbuch der konstruktiven Wissenschaftstheorie,* Mannheim, etc.: Bibliographisches Institut, Wissenschaftsverlag. (Contains the first part of Lorenzen and Schwemmer 1975, see below.)

Lorenzen, Paul and Kuno Lorenz (1978), *Dialogische Logik,* Darmstadt: Wissenschaftliche Buchgesellschaft. (The essential writings of Paul Lorenzen and Kuno Lorenz from the genesis of contemporary dialogical logic in 1958 to 1973.)

Lorenzen, Paul and Oswald Schwemmer (1975) *Konstruktive Logik Ethik und Wissenschaftstheorie,* 2nd improved ed. (first ed. 1973), Mannheim, etc.: Bibliographisches Institut, Hochschultaschenbücher Band 700. (The 'bible' of Erlangen Constructivism. The first part contains a mature exposition of Lorenzen's dialogical logic and the way it functions in the Erlangen program mentioned in Section 5.)

Machate, Joachim (1996), *Fokussierung im Dialog: Aspekte der Fokusintonation im Deutschen,* Berlin, etc,: Springer (dissertation, Stuttgart University; Forschung und Praxis 230).

Starmans, Richard J.C.M. (1996), *Logic, Argument, and Common Sense,* dissertation, Catholic University Brabant.

Strobel, Maria (1997), *Flexibilisierung und Beschränkung von Benutzeräusserungen innerhalb von telefonischen Mensch-Maschine Dialogen,* Heidelberg: IBM Deutschland, Scientific Centre, Institute for Logic and linguistics.

Valerius, Rolf D.H. (1990),*Die Logik von Rahmen- und Stopregeln in Lorenzen-Spiele,* dissertation, Stuttgart University.

Van Eemeren, Frans H., Rob Grootendorst, Francisca Snoeck Henkemans et al. (1996), *Fundamentals of Argumentation Theory: A Handbook of Historical Backgrounds and Contemporary Developments,* Mahwah, NJ: Lawrence Erlbaum. (Dialogue logic and formal dialectics are discussed in Chapter 9.)

Van Hoof, Antonius J.M. (1994), *Der logisch-pragmatischen Gebrauch von Konditionalsätzen: Eine dialog-logische Analyse,* Berlin, etc,: Springer (dissertation, Stuttgart University; Forschung und Praxis 216).

Vreeswijk, Gerard A.W. (1993), *Studies in Defeasible Argumentation,* dissertation, Free University, Amsterdam.

Walton, Douglas N. and Erik C.W. Krabbe (1995) *Commitment in Dialogue. Basic Concepts of Interpersonal Reasoning,* Albany, NY: State University of New York Press. (Pursues the integration of dialogical logic with other dialogue theory, especially Charles Hamblin's formal dialectic.)

Games in the Semantics of Natural Language

Gabriel Sandu

1 Games in the semantics of formal languages

Hintikka's 'Quantifiers vs. Quantificational Theory' (1973) was historically the first paper in the literature to discuss game-theoretical semantics (GTS) for natural language. A game-theoretical interpretation for formal languages was already formulated by Henkin (1961) who introduced both semantical games of perfect information as a natural interpretation for ordinary first-order formulas, and semantical games of imperfect information as a natural interpretation for Henkin or partially ordered quantifiers. Henkin pointed out that a sentence of the form $\forall x \exists y \forall z \exists w \varphi(x, y, z, w)$ where φ is a quantifier free formula can be interpreted by a game of perfect information played in a model M in the following way: Player $\forall$ chooses an individual a from the model, then player $\exists$ chooses b, after which player $\forall$ chooses c and finally player $\exists$ chooses d. Player $\exists$ wins the play if and only if $\varphi(a, b, c, d)$ is true in M. The sentence $\forall x \exists y \forall z \exists w \varphi(x, y, z, w)$ is true in M if and only if player $\exists$ has a winning strategy in the game, i.e. a method which tells him how to win a play of the game against any possible move of $\forall$. The winning strategy of $\exists$ is actually codified by two Skolem functions f and g.

In Henkin (1961), we also find a game-interpretation in which the information of the players is not complete (perfect). These games are associated with formulas containing Henkin quantifiers, i.e. formulas of the form

$$\begin{pmatrix} \forall x & \exists y \\ \forall z & \exists w \end{pmatrix} \varphi(x, y, z, w).$$

Henkin's idea was that the corresponding game is very similar to the game played with the sentence $\forall x \exists y \forall z \exists w \varphi(x, y, z, w)$: first player $\forall$ chooses a and c, and then player $\exists$ chooses b and d but when choosing b he is allowed to know only the choice a of his opponent, and when choosing d he is allowed to know only the choice c.

Henkin's game-theoretical intepretation for both ordinary quantifiers and partially ordered quantifiers was extended to cover also connectives and negation in Hintikka (1973). The game associated with $(\varphi_1 \vee \varphi_2)$ begins with $\exists$ choosing $i \in \{1, 2\}$ and then goes on as in the game associated with φ_i; the game associated with $(\varphi_1 \wedge \varphi_2)$ begins with $\forall$ choosing $i \in \{1, 2\}$ and then goes on as in the game associated with φ_i; finally, the game associated with $\neg\varphi$ is similar to the game played with φ, except that the players inverse roles. In addition to this extension, Hintikka also argued for the existence of Henkin quantifiers in English, e.g. in the sentences

> Some relative of each villager and some relative of each townsman hate each other.

> Some book by every author is referred to in some essay by every critic.

The question whether the above sentences should be analyzed as Hintikka proposed, i.e. as having the form $\begin{pmatrix} \forall x & \exists y \\ \forall z & \exists w \end{pmatrix} \varphi(x,y,z,w)$ arised a vivid discussion in the seventies, as witnessed by Stenius (1976), Gabbay and Moravcsik (1974), Guenthner and Hoepelman (1974), and Barwise (1979). Most linguists and logicians were not convinced by Hintikka's arguments.

¿From the point of view of the present paper, the question is less whether there are Henkin quantifiers in English or not but rather the impact of these quantifiers (in formal or natural languages) on the discussion of the principle of compositionality which is addressed in Barwise (1979), Hintikka and Sandu (1997), Sandu (1997), Janssen (1997), and Hodges (forthcoming). The discussion concerns both the games of perfect information and those of imperfect information.

The game-interpretation of ordinary first-order languages is clearly noncompositional. In other words, the semantical interpretation of first-order formulas by games of perfect information is not compositional. However, it is well known that under the axiom of choice the game-interpretation and the Tarski-type interpretation are equivalent and since the latter is compositional, the priciple of compositionality remains unquestioned.

In the case of games of imperfect information the issue of compositionality has raised more vivid discussions.

The idea of a partial ordering of quantifiers has been extended in Hintikka and Sandu (1989) to cover also partially ordered connectives. In these languages, called Independence-Friendly languages by Hintikka, the Henkin prefix is represented using a slash in the form $\forall x \forall z (\exists y / \forall z)(\exists w / \forall x)\varphi$, and instead of the existential quantifiers we may have other connectives. Barwise (1979) claims that partially ordered quantifiers cannot be interpreted compositionally in terms of the standard quantifiers $\forall$ and $\exists$. Similarly, Hintikka (1996) and Hintikka and Sandu (1997) claim that the idea of independent quantifiers and connectives violate the principle of compositionality. In view of these claims, the intriguing questions is whether the Independence-Friendly languages admit of a compositional semantics which stands to their game-theoretical semantics as Tarski-type semantics stand to the game-theoretical semantics for first-order languages. This question has been asked positively in two recent articles by Hodges (forthcoming).

2 Games in natural language

The applications of games to natural language have remained somehow restricted. With the exception of the work done by Esa Saarinen on backward-looking operators (Saarinen 1979), and Michael Hand on propositional attitudes (Hand 1986), most of the applications of GTS concern the analysis of quantifiers, and anaphora. But these developments require an extension of the traditional game-theoretical apparatus.

In case the language to be interpreted is a fragment of English things become more complicated. The sentences with which games are played are now syntactical trees, i.e. the derivational histories of these sentences. The choices of the players come now from a specific subset I of the universe of the relevant model. The choice set I actually codifies the context available to the players when they make their moves. Thus a game will not be any longer played only relative to a model M and an assignment g but also relative to a choice set I. Another difference with the games for formal languages is that the latter automatically ends up with an atomic formula. But in the former case, things are trickier. Consider the sentence

Example 1 *John owns a car. It is white.*

In this case the second sentence depends interpretationally on the first, so we cannot treat the dot as a standard conjunction and let player $\forall$ choose one of the conjuncts, because if he chooses the right one then the anaphoric pronoun *it* will lack a head and the whole sentence will not receive an interpretation. Instead we shall let the players play first a (sub)game associated with the first conjunct and after that play a (sub)game associated with the second.

The idea of subgame has been introduced in Hintikka and Carlson (1979) in connection with the treatment of conditionals in natural language. Since then it has proved to be very useful in the game-theoretical treatment of pronominal anaphora and anaphoric definite descriptions. The basic idea used over and over again in Hintikka and Kulas (1985) is that an anaphoric pronoun H has the head NP only if the semantic value of the NP is in the relevant choice when a rule of the game is applied to H. In a similar way, it is explained that in the sentence

Example 2 *John does not own a car. It is white.*

the impossibility of coreference between *it* and *a car* is due to the fact that the individual corresponding to the latter has to be introduced by the player who is the falsifier, and accordingly this individual is not in the choice set when the players move to play the second subgame.

As I pointed out, although the ideas of subgame and choice set have been in the trade for a long time (since Hintikka and Carlson (1979)), and used extensively in Hintikka and Gulas (1983, 1986), Hintikka and Sandu (1991), these notions have never been made very precise but use more or less heuristically. I made a first attempt towards the formalization of these concepts in Sandu (1997), but much work remains to be done. One of the advantages of a more technical treatments of the notions of subgame and choice set is that it makes GTS more comparable to some other semantical theories existing in the literature, like Discourse Representation Theory (DRT) and Dynamic Predicate Logic (DPL). I will devote the rest of the paper to these issues.

The basic idea in Sandu (1997) is to treat semantical games as formal objects of the model. Accordingly we shall have

- (M, g, S) is an atomic game, where M is a model (in the signature of S), g is an assignment for the free variables of the formulas in S.

- If G is a game, P_i rangers over one of the two players $\forall, \exists$,and $a_1, ..., a_n$ are arbitrary elements from the domain of M, then $(P_1 : a_1, ..., P_n : a_n, G)$ is a game.

- If $G_1$and G_2 are games, then so are $(G_1; G_2)$ (the conjunctive game) and $(G_1 \Rightarrow G_2)$ (the conditional game).

After the concepts *winning the game, the individuals introduced in the game, a strategy for a player in the game, using a strategy in the game, a player's having a winning strategy in the game* are defined, then we associate with every quadruple (M, g, S, I) a game, where M is a model in the signature of S, g is an assignment restricted to the free variables of the formula S,and the choice set or context I is a subset of individuals from the universe of M. We denote the game associated with (M, g, S, I) by $F(M, g, S, I)$. Let us look at some examples. We fix a model M an assignment g restricted to the set of relevant free variables, and a context I.

If A is an atomic formula, then $F(M, g, A, I)$ is just the atomic game (M, g, A).

If A is a formula of the form $A \rightarrow NP\ VP$, with NP being a proper name, then $F(M, g, S, I)$ is the game $(\exists : NP^M) \frown F(M, g \cup \{(x, NP^M)\}, VP(x), I \cup \{NP^M\})$.

If A is a formula having the form $A \rightarrow NP\ VP$ with $NP \rightarrow he_i$, is $(\exists : a) \frown F(M, g \cup \{(x, a)\}, VP(x), I)$, for some $a \in I$.

If A is a formula having the form $A \rightarrow A_1 A_2$ (or $A \rightarrow A_1 and A_2$) then $F(M, g, A, I)$ is $(G_1; G_2)$, where $G_1$is $F(M, g, A_1, I)$ and G_2 is $F(M, g, A_2, Ind^M(G_1))$, where $Ind^M(G_1)$ is the set of individuals introduced in the game G_1.

Applying these rules to the sentence

Example 3 *John smiles. He is happy*

the model M, the empty assignment $\emptyset$, and the empty context $\emptyset$,we end up with the conjunctive game:

$(\exists : John^M, (M, \{(x, John^M)\}, \{Smiles(x)\}));$

$((\exists : John^M, (M, \{(y, John^M)\}, \{Happy(y)\}))$

3 Comparisons with other frameworks

There is an obvious analogy between GTS and Discourse Representation Theory. Like the latter, GTS is a two-stage semantical process.

In the first stage sentences of natural language (or more exactly their derivational histories) are correlated with semantical games. In DRT the correlation is between sentences of natural language and Discourse Representation Structures. For instance, the resulting Discourse Representational Structure associated with our example above is$(j, c, Smiles(j), c = j, Happy(c)$, where j stands for the proper name *John*, andc stands for the pronoun *he*. Obviously, the two formulas $Smiles(x)$ and $Happy(y)$ in the resultive conjunctive game are the counterpart in GTS of the conditions $Smiles(j)$ and $Happy(c)$ in DRT but more about this matter will be said in the full paper. The question whether the first stage in DRT is compositional is still, in my opinion, an open question. The example I analyzed above should give you a flavor that this stage is compositional in GTS. However, the claim of the compositionality of GTS here is different from Hintikka's claim of its noncompositionality in Hintikka's earlier work. In this context, I will take up some of the related issues addressed in Janssen (1997).

In the second stage, game-theoretical truth is defined as the existence of a winning strategy for player ∃ in the semantical game. This stage is clearly noncompositional. In the second stage of DRT, truth is defined in a compositional way for the Discourse Representation Structures. A more thourough comparison between GTS and DRT will be undertaken in the full paper.

The dynamic aspect of GTS is codified by the changes in the choice set I. The differences with the dynamic predicate logic (DPL) approach in the style of Groenendijk and Stokhof (1991) and with DRT should be obvious. The dynamicity of the interpretation in GTS occurs at the first stage, i.e. the stage of the correlations between sentences and games. In DPL sentences of natural languages are correlated with forst-order formulas and these latter are given a dynamic interpretation. In the same spirit, in DRT Discourse Representation Structures may be given a dynamic interpretation as in van Eijck and Kamp (1997). In contrast, the dynamic aspect of GTS codified in the contextual change of the set I occurs at the first semantical stage.

References

Barwise, J., 'On branching quantifiers in English', *J. phil. logic* 8, pp. 47-80.

Gabbay, D., and Moravcsik, J.M.,1974, 'Branching quantifiers, English, and Montague grammar', *Theoretical Linguistics* 1, pp. 141-157.

Guenthner, F., and Hoepelman, L., 1974, 'A note on representing branching quantifiers', *Theoretical Linguistics* 1, pp. 285-289.

Groenendijk, J. and Stokhof, M., 1991, 'Dynamic predicate logic', *Linguistics and philosophy* 14, pp. 39-100.

Hand, M., 1986, 'Semantical games for negated belief attributions', *Theoretical linguistics* 13, pp. 211-223.

Hintikka, J., 1973, 'Quantifiers vs. Quantification Theory', Dialectica 27, pp. 329-358.

Hintikka, J., 1996, *The principles of mathematics revisited*, Cambridge University Press.

Hintikka, J. and Carlson, L., 1979, 'Conditionals, generic quantifiers, and other applications of subgames', in Saarinen (1979), pp. 179-214.

Hintikka, J. and Kulas, J., 1983, *The game of language*, D. Reidel, Dordrecht.

Hintikka, J. and Kulas, J., 1985,*Anaphora and definite descriptions*, D. Reidel, Dordrecht.

Hintikka, J. and Sandu G., 1989, 'Informational independence as a semantical phenomemnon', in J.E. Fenstad et al. (eds), *Logic, methodology and philosophy of science* VIII, Elsevier, Amsterdam, pp. 571-589.

Hintikka, J., and Sandu, G., 1997, 'Game-theoretical semantics', in Johan van Benthem and A. ter Meulen (eds.), *Handbook of logic and language*, Elsevier, Amsterdam pp. 361-410.

Hintikka, J. and Sandu G., 1991, *On the methodology of linguistics*, Basil Blackwell, Oxford.

Hodges, W., forthcoming, 'Compositional semantics for a language of imperfect information'.

Janssen, T.M.V., 1997, 'Compositionality' in Johan van Benthem and A. ter Meulen (eds.), *Handbook of logic and language*, Elsevier, Amsterdam pp. 417-474.

Saarinen, E., 1979, 'Back-looking operators in Tense logic and in natural language', in Jaakko Hintikka, Ilkka Niiniluoto and Esa Saarinen (eds.), *Essays on mathematical and philosophical logic*, D. Reidel, Dordrecht, 1979, pp. 341.367.

Saarinen, E. (ed.), 1979, *Game-theoretical semantics*, D. Reidel, Dordrecht.

Sandu, G., 1997, 'On the theory of anaphora: Dynamic predicate logic vs. game-theoretical semantics', Linguistics and philosophy 20, pp. 147-174.

Stenius, E., 1976, 'Comments on Jaakko Hintikka's paper "Quantification vs. Quantificational theory" ', Dialectica 30, pp. 67-88.

Van Eijck, J, and Kamp, H., 1997, 'Representing discourse in context', in Johan van Benthem and A. ter Meulen (eds.), *Handbook of logic and language*, Elsevier, Amsterdam pp.179-238.

Topic, Focus and the Interpretation of Bare Plurals

Ariel Cohen & Nomi Erteschik-Shir
Ben Gurion University, Israel

It is well known that bare plurals (BPs) can receive generic or existential readings:

(1) a. Boys are brave. b. Boys are hungry.

Sentence (1.a) gets only a generic reading, namely that boys, in general, are brave. Sentence (1.b), on the other hand, is ambiguous; it can also receive a generic reading, namely that boys, in general, are hungry, but the dominant reading is existential: there are some hungry boys.

In this paper we argue that an account of topic and focus is crucial to the interpretation of BPs. In particular, generically interpreted BPs are topics, and nongenerically interpreted BPs are foci. The latter, we claim, are not existentially quantified variables, as is usually assumed, but are incorporated into the predicate and carry an implicature of suitability with respect to the topic.

1. The Problem

Most recent approaches (Diesing 1992; Kratzer 1995; Chierchia 1995) to the phenomenon exemplified by (1) follow Carlson (1977) in drawing a distinction between two types of predicate: individual-level predicates, exemplified by *brave*, and stage-level predicates, exemplified by *hungry* (henceforth I-level and S-level, respectively). According to these theories, subjects of the former receive generic readings only, whereas subjects of the latter may receive either generic or existential readings.

However, these readings are not freely available; in fact, sometimes only one of the readings is available:

(2) That's what I hate about little boys. No matter how much they eat, they are hungry.

(3) Boys are hungry in the dining room right now.

Sentence (2) can only be interpreted generically, whereas (3)—only existentially. Neither Diesing and Kratzer nor Chierchia offer an account of these facts.

Subjects of I-level predicates are predicted by Diesing, Kratzer and Chierchia to receive generic readings only. However, if the subjects are stressed, existential readings are sometimes available.

(4) a. LAWYERS know John. b. CRIMINALS own this club.

Both these approaches face additional difficulties dealing with the readings of objects of I-level verbs. According to Diesing's and Kratzer's theories, material inside the VP is interpreted existentially; hence, such objects are predicted, *prima facie*, to receive existential readings only. According to Chierchia, I-level predicates require the presence of the generic quantifier, which binds the NPs in its scope; hence, such objects would be predicted to receive generic readings only. As it turns out, objects of some verbs (e.g. *hate*) receive generic readings only, whereas objects of other verbs are ambiguous, and their preferred reading is existential:

(5) a. John hates lawyers. b. John knows lawyers.

To account for this phenomenon, Diesing and Kratzer suggest that some objects may optionally scramble out of the VP at LF, to be bound by the generic quantifier. However, they fail to explain why some objects scramble and some do not.

2. Focus Structure

We argue that in order to derive the correct interpretations of the sentences in (1), a theory of topic and focus is required. We adopt the theory of focus structure of Erteschik-Shir (1997, in press): structural descriptions annotated for Topic and Focus provide the input to semantic interpretation. We assume a model of discourse which makes use of a set of file cards which represent discourse referents. This file is organized according to the topics defined by the discourse referents.

Cards are created and manipulated in accordance with the following rules:

1. TOPIC instructs the hearer to locate on the top of his file an existing card with the relevant heading and index.
2. FOCUS instructs the hearer to either:
   (a) for an indefinite NP: open a new card and put it on the top of the file. Assign it a heading and a new index.
   (b) for a definite NP: locate an existing card and put it on the top of the file.
3. PREDICATION instructs the hearer to evaluate the main predicate with respect to the topic, where the predicate is taken to be the complement of the topic.[1]

Note that it follows from the TOPIC rule that topics are necessarily specific.

Since truth values are evaluated with respect to the topic, every sentence must have a topic. "Out of the blue" sentences are often claimed to be topicless:

(6) a. It is raining. b. A man arrived.

We argue that they do, in fact, have a topic, namely the current here-and-now of the discourse. Such a topic we refer to as a Stage Topic. A card for the current stage is therefore always available on top of the file and its referent is determined by the temporal and spatial parameters of the discourse.

3. Interpretation of Bare Plurals

When BPs are topics, they are interpreted generically. This is so because topics must be specific, and for a BP to be specific, it must refer to a kind. Characterizing generics involve a phonologically null quantificational adverb, **gen**. In order to avoid type mismatch, the kind is type-raised to introduce a variable, denoting a representative of the kind, to be bound by **gen**.[2] For example, the logical form of (7.a) is (7.b) (where C is

[1] If the result of the evaluation is TRUE then the file is updated with the new information.

[2] See Cohen 1996 for the details.

the representation relation, and $\uparrow$**bird** is the kind of birds):

(7) a. Birds fly. b. $\mathbf{gen}_{x;}[C(x, \uparrow\mathbf{bird})][\mathbf{fly}(x)]$

We thus explain Chierchia's (1992) observation that the topic forms the domain of quantification.

Focused BPs, in contrast, receive existential readings. If we hold the position that BPs are indefinite, we can propose a simple account of this fact: the FOCUS rule applies, resulting in the existential force of BPs. We can thereby explain Laca's (1990) observation that topics receive a generic interpretation and foci—an existential one.

4. Individual-Level and Stage-Level Predicates

We follow Diesing and Kratzer in proposing that S-level predicates, but not I-level ones, have a spatiotemporal argument. This argument, we claim, is a stage topic.

We can now account for the various readings of BPs exhibited in (1). In (1.a), since there is no stage topic, *boys* is necessarily the topic and must therefore be specific—referring to the kind of boys—resulting in the generic reading.

(8) $\mathbf{gen}_{x;}[C(x, \uparrow\mathbf{boy})][\mathbf{brave}(x)]$

Unlike (1.a), (1.b) allows a stage topic. Consequently, *boys* is not necessarily in topic position and may receive an existential reading.

A fact unnoticed by most researchers is that, uttered out of the blue, (1.b) is actually quite awkward. The reason is that, without context, there is no stage topic available, except for the rather vague here and now. Adding a clear stage topic, as in (3) above and (9) below, makes the existential reading much easier to get:

(9) Lunch was served late yesterday and in the dining room boys were hungry.

When the BP is a topic, we receive a generic reading, as in (2) above. We argue, *contra* Chierchia (1995), that the mere presence of an unselective quantifier is not sufficient for a generic reading. The subject of (10.a) is interpreted existentially rather than generically (though still inside the scope of *always*), as can be seen by the fact that (10.a) is entailed by (10.b):

(10) a. Plumbers are always available. b. Efficient plumbers are always available.

5. Discourse and Intonation

Kratzer (1995) admits that focus interacts with the interpretation of BPs. She notes that, when stressed, *COUNTEREXAMPLES* receives an existential interpretation in (11), although it is an argument of an I-level predicate:

(11) She thinks that COUNTEREXAMPLES are known to us.

However, Kratzer denies that BP interpretation is fully determined by focus as we do. Kratzer points out that focusing the subject in (12) still results in a generic rather than an existential reading:

(12) FIREMEN are altruistic.

However, note that the generic reading of *FIREMEN* is only licensed in a contrastive context in which firemen are contrasted with plumbers, say. In this case we argue that the subject constitutes a contrastive topic, rather than focus, and its topichood forces the generic reading. Note that when a stage topic or an individual (object) topic is available, the BP subject can be (noncontrastively) focused and receive an existential reading:

(13) a. FIREMEN are available. b. FIREMEN own Microsoft.

6. Incorporation

In the discussion above, we have derived the existential readings of BPs via the FOCUS rule, i.e. by treating them as indefinites, a path taken by Diesing and Kratzer, following many others. This, however, is problematic, as there are a number of differences between BPs and real indefinites.

In particular, as noted by Carlson (1977), BPs receive narrow scope only. While (14.a) is ambiguous between narrow and wide scope readings of its object, the object of (14.b) can only receive narrow scope:

(14) a. Everyone read a book on giraffes. b. Everyone read books on giraffes.

Carlson proposes that the object BPs are incorporated into the verbs. This proposal has been developed further by van Geenhoven (1996) (see also McNally forthcoming). According to her, BPs denote properties; they get their existential force lexically, by getting incorporated by the verb, hence their narrow scope. Thus, for example:

- $[\![\text{spots}]\!] = \lambda y.\mathbf{spot}(y)$
- $[\![\text{see}]\!] = \lambda P.\lambda x.\exists y : P(y) \wedge \mathbf{see}(x, y)$
- $[\![\text{John saw spots}]\!] = \exists y : \mathbf{spot}(y) \wedge \mathbf{see}(\mathbf{John}, y)$

We do not take incorporation to be syntactic, since it does not require adjacency—indirect objects also receive narrow scope only:

(15) Everyone read Cinderella to sick children.

The same holds for subject BPs, as noted by Carlson (1977).

Also, it is important to relate the two versions of a verb in a principled way: the incorporating version, which applies to properties, and the nonincorporating one, which applies directly to individuals. The solution is to require that a verb applies to individuals, as usual. When any of the arguments, regardless of syntactic position, denotes a property, it is incorporated by Partee's (1987) type-shifting operator A:

- $\mathbf{see}(\mathbf{John}, \mathbf{spot}) \Longrightarrow \exists y.\mathbf{spot}(y) \wedge \mathbf{see}(\mathbf{John}, y)$

If BPs are not indefinite, but rather incorporated into the predicate, the FOCUS rule does not apply, only the PREDICATION rule. Consequently, we predict that incorporated BPs do not introduce discourse referents. In contrast, van Geenhoven's existential operator is dynamic, resulting in discourse referents.

We claim that our prediction is borne out. One indication that nongeneric BPs do not introduce discourse referents is that they can only give rise to so called maximal anaphora. While the sentences in (16) leave open the possibility that additional men came in but did not sit down, (17) entails that *all* men who came in sat down:

(16) a. A man came in. He sat down. b. Some men came in. They sat down.

(17) Men came in. They sat down.

7. Suitability

Consider another difference between BPs and indefinites:

(18) a. This tractor has $\left\{ \begin{array}{l} \text{a wheel.} \\ \text{some wheels.} \end{array} \right\}$ b. This tractor has wheels.

If the tractor has only two wheels, (18.a) would be unproblematically true. In fact, (18.a) implicates that it does not have all its wheels. Not so with (18.b); if the tractor has only two wheels, (18.b) would be odd; the tractor must have all its wheels for (18.b) to be felicitous. In fact, it is not sufficient that this tractor simply have four wheels, but rather it must have the right kind of wheels: two large rear wheels, and two smaller front wheels. BPs implicate, then, that their denotation is, in some sense, *suitable* with respect to the topic. Different topics will give rise to different suitability implicatures:

(19) This tractor/car/bicycle/unicycle/tricycle has wheels.

This suitability implicature cannot be expressed, let alone explained, by the current formalism. We argue, therefore, that BPs denote not simple properties, but properties of pluralities, and that these pluralities are implicated to be suitable:

- $[\![\text{wheels}]\!] = \lambda Y.\mathbf{wheels}(Y)$
- $[\![\text{have}]\!] = \lambda y.\lambda x.\mathbf{have}(x, y)$
- $\mathbf{have}(\mathbf{this\text{-}tractor}, \mathbf{wheels}) \Longrightarrow \exists Y.\mathbf{wheels}(Y) \wedge \mathbf{have}(\mathbf{this\text{-}tractor}, Y)$

The suitability implicature is what gives rise to quasi-universal readings of BPs (Greenberg 1994):

(20) a. (In this country) lakes are empty. b. (In this army) soldiers are tired.

Sentence (20.a), for example, is not felicitous if only one or two lakes, or only the lakes in the south of the country, or only lakes smaller than a certain size, are empty. This is because for a set of lakes to be a suitable set associated with the country, it needs to be sprinkled more or less evenly throughout the whole of the country.

8. Nonincorporating Verbs

This theory still does not account for why some verbs, e.g. *hate*, apparently fail to incorporate, as can be seen by (5) above. We claim that the solution comes from the fact that an incorporating verb must give rise to a suitability implicature. Hence, such verbs must define the relevant association with the topic which provides the criterion for suitability. A verb like *know* can define an association: for every individual x, x is associated with John iff John knows x. This can be used as one definition of association, since for every x it is either true or false that John knows x.

A verb like *hate*, on the other hand, does not define association, but rather presupposes it. There are individuals x for which it is neither true nor false that John hates x, namely those individuals whom John does not know. John's hating x, then, presupposes John's knowing x, i.e. presupposes, rather than defines, an association between John and x. *Hate*, therefore, cannot be used to define an association, and hence cannot give rise to a suitability implicature and cannot incorporate.

9. Conclusion

We argue for an account of the interpretation of BPs based on the distinction between topic and focus. We claim that BP topics are specific, refer to kinds and are type-raised to be bound by the generic quantifier. BP foci, on the other hand, denote properties of pluralities, are incorporated into the predicate and receive existential readings and give rise to suitability implicatures. We believe our account is preferable to others in its empirical coverage. Moreover, in addition to providing the correct readings of the BPs, we also predict the intonation and the context associated with each reading.

References

CARLSON, G. 1977. *Reference to Kinds in English.* University of Massachusetts at Amherst dissertation. Also published 1980, New York: Garland.

CARLSON, G., and PELLETIER, F. J. (eds.) 1995. *The Generic Book.* Chicago: University of Chicago Press.

CHIERCHIA, G. 1992. Anaphora and dynamic binding. *Linguistics and Philosophy* 15.111–183.

—— 1995. Individual-level predicates as inherent generics. In Carlson and Pelletier (1995) 176–223.

COHEN, A. 1996. *Think Generic: The Meaning and Use of Generic Sentences.* Carnegie Mellon University dissertation.

DIESING, M. 1992. *Indefinites.* Cambridge, Massachusetts: MIT Press.

ERTESCHIK-SHIR, N. 1997, in press. *The Dynamics of Focus Structure.* Cambridge: Cambridge University Press.

VAN GEENHOVEN, V. 1996. *Semantic Incorporation and Indefinite Descriptions.* University of Tübingen dissertation.

GREENBERG, Y. 1994. Hebrew nominal sentences and the stage/individual level distinction. Master's thesis Bar-Ilan University.

KRATZER, A. 1995. Stage-level and individual-level predicates. In Carlson and Pelletier (1995) 125–175.

LACA, B. 1990. Generic objects: Some more pieces of the puzzle. *Lingua* 81.25–46.

MCNALLY, L. forthcoming. Stativity and theticity. In *Events and Grammar*, ed. by S. Rothstein. Dordrecht: Kluwer.

PARTEE, B. H. 1987. Noun phrase interpretation and type-shifting principles. In *Studies in Discourse Representation Theory and the Theory of Generalized Quantifiers*, ed. by J. Groenendijk, D. de Jongh, and M. Stokhof 115–143. Dordrecht: Foris.

Presuppositions and backgrounds

Bart Geurts (University of Osnabrück)
Rob van der Sandt (University of Nijmegen)

Focusing divides the content of a sentence, as uttered on a given occasion, into two parts: focus and background. E.g.,

(1) [Fred]$_F$ robbed the bank.

Here the focus is the semantic correlate of 'Fred'; the background is the semantic correlate of '___ robbed the bank', which may be an open proposition, a property, or whatever. At any rate, taken on its own the background of (1) does not entail that someone robbed the bank. We believe that this is presupposed, and that this presupposition is induced by the focus/background division. More generally, we want to consider the hypothesis that the following principle holds:

(2) *The Background/Presupposition Rule (BPR)*
Whenever φ is backgrounded, the presupposition is triggered that φ^* holds, where φ^* is the existential instantiation of φ.

Although this particular formulation is our own, the BPR is not exactly new; it is very much in the spirit of Jackendoff (1972), for example. In more recent times, very few authors have endorsed anything like the BPR, and we concede that, prima facie at least, the principle has its problems. However, in this paper we want to focus on the merits of the BPR, because it seems to us that its explanatory potential is often underestimated.

The main point that we want to argue for in this paper is the following. There is a whole range of focusing phenomena that either have been neglected in the literature or have been explained with the help of ad hoc principles. The BPR allows us to explain all of these phenomena in terms of presupposition projection.

The presupposition theory we adopt is the one proposed by van der Sandt (1992); it is an extension of DRT. The main tenet of the 'binding theory' of presupposition projection, as we call it, is that presuppositions are the kind of entities that want to be bound, just as anaphors want to be bound. As a matter of fact, according to the binding theory anaphors *are* presuppositional expressions. The only difference between anaphors and most (other) varieties of presupposition is that the former must be bound to a given antecedent whereas the latter often can be interpreted by way of accommodation. In general, if a presupposition cannot be bound, a suitable antecedent will be accommodated, i.e. an antecedent will be set up in some position which is accessible from the DRS in which the presupposition was triggered. Accommodation is subject to a number of constraints: accommodation must yield a coherent interpretation and by default a presupposition will be accommodated as closely to the main DRS as is possible while maintaining coherence, i.e. global accommodation is preferred to local accommodation.

Projection

If the BPR is correct, then focusing should give rise to the projection behaviour that is the hallmark of presuppositions. This turns out to be the case, as the following observations illustrate:

(3) a. If $[\text{Fred}]_f$ robbed the bank, then Barney helped him.
b. If Barney wasn't in town, then $[\text{Fred}]_f$ robbed the bank.
c. If anybody robbed the bank, then $[\text{Fred}]_f$ robbed the bank.

While (3a) and (3b) would normally imply that someone robbed the bank, (3c) would not imply this. Hence this implication behaves exactly as the presupposition triggered by, e.g., a factive verb would behave. Cf.:

(4) a. If Fred knows that someone robbed the bank, then he will assume that Barney did it.
b. If he has seen the newspapers, then Fred knows that someone robbed the bank.
c. If someone robbed the bank, then Fred knows that someone robbed the bank.

While (4a) and (4b) would normally imply that someone robbed the bank, (4c) would not imply this. The pattern is exactly the same as in (3), and since it is widely accepted that in this case an analysis in presuppositional terms is called for, the same should hold for (3).

In conjunction with the binding theory, the BPR accounts for the data in (3) as follows. First, consider (3c). We assume that the grammar associates the following DRS with this sentence (ignoring all irrelevant details):

(5) [: [u: u robbed the bank] ⇒ [: Fred robbed the bank]]

In view of the focus/background division of the consequent of (3c), the BPR entails that in (5) the presupposition is triggered that someone stole the bank, which we represent as follows:

(6) [: [u: u robbed the bank] ⇒ [<u>v</u>: <u>v robbed the bank</u>, Fred robbed the bank]]

The binding theory predicts that this presupposition prefers to be bound, and as it can be bound in the antecedent of the conditional, we obtain the following reading for this sentence:

(7) [: [u, v: u robbed the bank, v robbed the bank, v = u] ⇒ [: Fred robbed the bank]]

Thus the presupposition that someone robbed the bank is 'absorbed' in the antecedent of the conditional. In (3a) and (3b), on the other hand, this presupposition cannot be bound, and therefore it must be accommodated. The binding theory predicts that, in such cases, global accommodation is preferred to local accommodation, and we obtain the following readings for (3a) and (3b), respectively:

(7) a. [v: v robbed the bank, [: Fred robbed the bank] ⇒ [: Barney helped Fred]]
b. [v: v robbed the bank, [: Barney wasn't in town] ⇒ [: Fred robbed the bank]]

To sum up: the existential inferences licensed by focusing exhibit the projection behaviour that is typical of presuppositions, and the BPR explains this.

'Only'

Although 'only' is a controversial word, the controversy is not about the information that sentences with 'only' convey. Practically everybody would agree, e.g., that (9) conveys the information that Muriel voted for Hubert and that apart from Muriel nobody else voted for Hubert:

(9) Only Muriel voted for Hubert.

The main issue is what parts, if any, of the information conveyed by (9) are entailed, presupposed, implicated, and so on. If we adopt the BPR and the binding theory, however, we can make do with a minimal semantics for 'only' (in fact, it is just the semantics proposed by Geach 1962): it suffices to specify that 'only *a* φ' means that it is not so that someone else than *a* has the property φ. Thus the 'conventional meaning' of (9) is the following:

(10) [: ¬[u: u voted for Hubert, u ≠ Muriel]]

As the grammar of 'only' requires that 'Muriel' is the focus, the semantic correlate of '___ voted for Hubert' is background information, and the BPR implies that the corresponding presupposition is triggered in the scope of the negation operator, as shown in (11a):

(11) a. [: ¬[u, <u>v</u>: <u>v voted for Hubert</u>, u voted for Hubert, u ≠ Muriel]]
b. [v: v voted for Hubert, ¬[u: u voted for Hubert, u ≠ Muriel]]

The binding theory predicts that, in the absence of a suitable antecedent, this presupposition is preferably accommodated in the main DRS. Hence the default interpretation of (9) should be (11b), which is correct.

If this analysis is on the right track, then 'only *a* φ' gives rise to the presupposition that there is an *x* such that φ(*x*), but this presupposition is *not* triggered by the lexical content of 'only': its source is the focus/background division of the sentence (which in its turn is constrained by the grammar of 'only').

In (9) the presupposition is accommodated globally, and as long as a binding interpretation is not available, this option is strongly preferred. There are however related cases in which the option of local accommodation is exercised. E.g.,

(12) a. Only Rumpelstiltskin may kiss me.
b. [: ¬[u, <u>v</u>: <u>v may kiss the speaker</u>, u may kiss the speaker, u ≠ Rumpelstiltskin]]
c. [v: v may kiss the speaker, ¬[u: u may kiss the speaker, u ≠ Rumpelstiltskin]]

In a context in which it is taken for granted that there is no such person as Rumpelstiltskin, (12a) is a way of conveying that *nobody* is allowed to kiss the speaker.

This reading comes about as follows. The semantic representation of (12a) is of course analogous to that of (9), and after the BPR has applied we have (12b), which mirrors (11a). Suppose now that, as in the previous example, this presupposition is accommodated globally, as shown in (12c). Given that it is part of the common ground that there is no such person as Rumpelstiltskin, this reading would be inconsistent, and therefore the hearer decides to accommodate the presupposition locally. So (12b) represents the final interpretation of (12a).

Our analysis of the following example is along the same lines:

(13) Only Kim can pass the test, and it's possible even she can't. (Horn 1996)

Global accommodation of the presupposition that someone can pass the test would cause a conflict with the second half of this statement, and therefore the presupposition is accommodated locally.

Domain restriction

It is a well-established fact that the focus/background division within a quantifier's nuclear scope affects the interpretation of the quantificational domain. Roughly speaking: backgrounded material in the nuclear scope is interpreted as part of the quantifier's restrictor, while focused information remains part of the nuclear scope. Thus the most likely interpretation of (14a) is (14b):

(14) a. Fred always drinks $[\text{milk}]_F$.
b. Always, if Fred drinks something, he drinks milk.

The BPR accounts for this as follows . Let us assume that adverbial quantifiers range over events (other accounts of adverbial quantification could be accommodated, too). Then (14a) is represented as follows:

(15) [: [e:]⟨all e⟩[: Fred drinks milk in e]]

Since in (14a) 'milk' is focused, and the remaining material in the scope of 'always' is backgrounded, the BPR predicts that the following presupposition is triggered:

(16) [: [e:]⟨all e⟩[<u>u</u>: <u>Fred drinks u in e</u>, Fred drinks milk in e]]

Since this presupposition cannot be bound, it must be accommodated, but in this case global accommodation is not an option, because the presupposition contains a reference marker that is introduced in the restrictor of the universal quantifier. Since the general constraint is that accommodation in the least embedded DRS is preferred, it follows that the presupposition must be accommodated in the restrictor of the quantifier, and thus we obtain the following reading for (14a):

(17) [: [e, u: Fred drinks u in e]⟨all e⟩[: Fred drinks milk in e]]

Note, again, that this result is obtained without the help of any special rules of principles: it follows directly from the BPR and the binding theory. (For further discussion of this analysis, as well as a more refined treatment of quantificational phenomena, see Geurts and van der Sandt, to appear; see Beaver (1995) for an analysis which relates domain restriction in quantificational constructions to the notion of discourse topic).

Negation

Whenever focusing appears to affect the interpretation of a given expression or construction, there is a tendency in the more recent literature to infer that some form of quantification must be involved. For instance, in an attempt to explain the fact that the interpretation of negation is sensitive to focus, Kratzer (1989) proposes to analyse negation as quantification. The following pair of examples is Kratzer's:

(18) a. Paula isn't registered in $[\text{Paris}]_F$.
b. $[\text{Paula}]_F$ isn't registered in Paris.

(18a) and (18b) have different interpretations: (18a) implies that Paula is registered somewhere, and (18b) implies that someone is registered in Paris. Kratzer (1989) observes that such inferences 'are typical for certain quantifier constructions', and argues on this basis that negation is a form of quantification, too, which is to say that negation has a quantificational domain and a nuclear scope, just as 'all' or 'most', for example. This conclusion is easily avoided once it is realised that the inferences observed in (18) are *not* peculiar to quantifier constructions but conform to the much more general principles of presupposition projection: if we adopt the BPR, these observations are predicted by the binding theory without further ado (indeed, they should be predicted by any projection theory worth its salt).

In (18a, b) the presuppositions triggered via the BPR are accommodated globally. The following example illustrate that such presuppositions may be accommodated locally, too:

(19) a. $[\text{Fred}]_F$ didn't rob the bank.
b. I'm not at all convinced that the bank has been robbed, but (I am certain that) $[\text{Fred}]_F$ didn't rob the bank.

In the absence of contrary evidence, the default interpretation of (19a) is analogous to that of (18b). But in the context of (19b), there is evidence that the speaker does not assume that someone robbed the bank, and therefore this presupposition will remain within the scope of the negation operator. (For further discussion of the interaction between presuppositional expressions and negation, see Geurts, to appear).

Counterfactuals

As Dretske (1972) was the first to point out, the interpretation of counterfactuals (and certain related constructions) is focus sensitive. (20a, b) are Dretske's examples:

(20) a. If Clyde hadn't married $[\text{Bertha}]_F$, he would not have been eligible for the inheritance.
b. If Clyde hadn't $[\text{married}]_F$ Bertha, he would not have been eligible for the inheritance.

Dretske maintains that these sentences have different truth conditions. We are not so sure about this, but agree that there are contexts in which one of these sentences would be true and the other grossly inappropriate, or vice versa. In any event, this difference is explained by the BPR. Modulo focusing, (20a, b) can both represented as in (21), where '>' is, say, Lewis's (1973) conditional necessity operator transposed into DRT:

(21) [: [: ¬[: Clyde married Bertha]] > [: Clyde is ineligible for the inheritance]]

When focusing is taken into account, the interpretations of (20a) and (20b) will diverge, because different presuppositions are triggered according to the BPR. In both cases, the binding theory predicts that the presupposition in question is accommodated in the main DRS, and thus the resulting interpretations are (22a) and (22b), respectively:

(22) a. [u: Clyde married u, [: ¬[: Clyde married Bertha]] > [: Clyde is ineligible for the inheritance]]
b. [v: Clyde v'd Bertha, [: ¬[: Clyde married Bertha]] > [: Clyde is ineligible for the inheritance]]

It is evident that these DRSs have different truth conditions, and Dretske's observation that (20a) and (20b) have different interpretations (in a sufficiently loose sense of 'interpretation') is accounted for. In Dretske's scenario, Clyde is a dedicated bachelor, who wouldn't consider marrying anyone but Bertha, because she lives abroad eleven months a year. In this situation, the reading represented by (22b) is appropriate, but the one represented by (22a) is not, because it presupposes, in effect, that Clyde would have married no matter what.

References

Beaver, D. 1995: *Presupposition and Assertion in Dynamic Semantics*. PhD Thesis. University of Edinburgh, Edinburgh.

Dretske, F.I. 1972: Contrastive statements. *Philosophical Review* 81: 411-437.

Geach, P.T. 1962: *Reference and Generality*. Cornell University Press, Ithaca, NY.

Geurts, B. to appear: The mechanisms of denial. *Language*.

Geurts, B. and R.A. van der Sandt, to appear: Domain restriction. In: P. Bosch and R.A. van der Sandt (eds.), *Focus: Linguistic, Cognitive, and Computational Perspectives*. Cambridge University Press.

Horn, L.R. 1996: Exclusive company: 'Only' and the dynamics of vertical inference. *Jorunal of Semantics* 13: 1-40.

Jackendoff, R. 1972: *Semantic Interpretation in Generative Grammar*. MIT Press, Cambridge, Mass.

Kratzer, A. 1989: An investigation of the lumps of thought. *Linguistics and Philosophy* 12: 607-653.

Lewis, D.K. 1973: *Counterfactuals*. Harvard University Press, Cambridge, Mass.

Van der Sandt, R.A. 1992: Presupposition projection as anaphora resolution. *Journal of Semantics* 9: 333-377.

Topic-Focus Articulation in SDRT

Ivana Kruijff-Korbayová & Geert-Jan M. Kruijff

1. Introduction

The work described here is part of a larger effort to develop a theory of discourse representation for Czech based on the Praguian framework of Functional Generative Description (FGD, [Sgall et al., 1986]). We depart from FGD in that we aim at a framework for analysis. Given an utterance of a sentence in a discourse, we want to analyze that sentence through a process of (1) constructing its tectogrammatical representation(s) reflecting the meaning potential of the sentence, and (2) building an interpretation with respect to the larger context in which the sentence occurs. In this paper we will be concerned with the latter process that takes a tectogrammatical representation (TR) of a sentence as an input and yields a TFA-sensitive interpretation of an utterance of a sentence anchored in a larger discourse context.

We aim on the one hand to extend the Praguian framework with a treatment of discourse phenomena, and on the other hand to modify the discourse representation theory by taking information structure into account. Since the information structure of a sentence, in FGD referred to as the topic-focus articulation (TFA), is one of the essential notions reflected in the TR, it is possible to exploit it in the course of further processing. We propose a modification of the basic DRT fragment [Kamp and Reyle, 1993] which serves as the first step in developing a TFA sensitive version of Asher's SDRT [Asher, 1993].

Our approach shares some underlying ideas with the approach advocated by Vallduví [Vallduví, 1994]. One difference between our approaches is a difference in the description of information structure: whereas in Vallduví 's information packaging one works with the ground-focus dichotomy in which the ground may be further subdivided into a link and a tail, the TFA in FGD is seen as the topic-focus dichotomy without any further subdivision, but with an ordering of the items included in the topic and in the focus along the scale of communicative dynamism. Furthermore, the two approaches differ in respect of which sentences are classified as all-focus. In the example below, (1a) shows the information packaging accordingg to Vallduví, and (1b) shows the topic-focus dichotomy according to FGD.

What can you tell me about the president? He likes BROCOLI.

(a) $[_F$ he likes BROCOLI$]$

(b) $[_T$ he$]$ $[_F$ likes BROCOLI$]$

Our approach to discourse representation differs from Vallduví's in that we employ the DRT-based perspective rather than the file-change metaphor. We treat the topic of a sentence as presupposed material which needs to be anchored in the representation of the disocurse built so far. In terms of our modifcation of DRT, topic-focus articulation plays a role in determining the appropriate attachmentsite and it can constrain the discourse relation used in attachment.

In the rest of this abstract we proceed as follows. We overview some of the essential notions and intuitions originating from the FGD framework. We define a translation of a subset of the TRs into corresponding pseudo-logical forms inspired by Peregrin's [Peregrin, 1995], called the *λ-TRs*. A λ-TR represents the topic-part and focus-part of a sentence by two related λ-expressions. We then define construction of a sentence-DRS out of a λ-TR and we sketch the conditions for attaching a sentence-DRS to an existing DRS. Due to the restricted length of this abstract, we cannot present all the necessary formal specifications.

2. Tectogrammatical representation

The FGD framework defines a dependency grammar approach to the description of language [Sgall et al., 1986]. FGD works with several levels of representation, one of which is the tectogrammatical representation which represents the linguistic meaning. A TR is a structure that captures (i) *syntactico-semantic relations* between lexical items, reflecting their dependency and coordination relationships, (ii) the *distinction between contextual boundness and non-boundness* for each lexical item which indicates whether an item relates to already established context or is a modification or extension of it, and (iii) the *scale of communicative dynamism*, reflecting deep (underlying) word order.[1]

Henceforth, we shall use a linearized form to write down TRs. The TR of the sentence in (1) is written as follows:

(1′) [[ACT:he^{cb}] ROOT:like^{nb} [PAT:brocoli^{nb}]]

3. Topic-focus articulation

In FGD, the *topic-focus articulation* (TFA) is a secondary notion defined as a dichotomy derived on the basis of countextual boundness. For primary cases, TFA is specified as follows [Sgall et al., 1986]:

(i) The main verb belongs to the focus iff it is contextually nonbound (NB), and to the topic iff it is contextually bound (CB).
(ii) The NB nodes depending on the main verb belong to the focus, and so do all nodes that are subordinated (transitively dependent) to these NB nodes.
(iii) If some of the elements of the TR belong to the focus, as according to (i) and (ii), then every CB node dependent on the main verb, together with all the nodes subordinated (transitively dependent) to these nodes, belong to the topic.
(iv) If no node of the TR fulfils (i) nor (ii), then the focus is probably more deeply embedded.

We do not need a more complex definition for the purpose of this paper.

4. From TR to λ-TR

In a recent article [Peregrin, 1995], Peregrin proposed extensional semantics of formulas of the form P{S}, as the predication of P, corresponding to the focus-part of a sentence, of S, corresponding to its topic-part. His approach offers a formalization of the intuition that the topic of a sentence is what the sentence is about and the focus is what the sentence says about its topic, that the topic is connected with a presupposition and that focus tends to be interpreted as exhaustive. In the following section we sketch how we take Peregrin's proposal further.

We define λ-TRs of the form $F\{T\}$ which serve as an intermediate step between a TR and a TF-DRS.Our λ-TRs preserve the structure of a TR which is relevant for further processing.

In the current paper we confine ourseves to the *nucleus TRs*, i.e. the TRs which consist only of the *nucleus* and no other nodes. The TR nucleus consists of the root-node of the TR, corresponding to the main verb of the sentence, and the nodes directly dependent on it corresponding to complementations of the verb realized by nouns (in various cases, expressed with or without a preposition) or adverbs. An example of a nucleus TR is shown in (1′) above.

The nominal complementations can correspond to the inner participants, i.e. depending on the verb as the ACTOR (ACT), PATIENT (PAT), ADDRESSEE (ADR), ORIGIN (ORI), EFFECT (EFF), or to the free modifiers expressed by prepositional

[1] A more detailed introduction to FGD can be found in Kruijff's paper in these proceedings.

noun groups, e.g. LOCATION (LOC), DIRECTION (DIR), INSTRUMENT (INS), TIME (TM), MANNER (MNR). The adverbial complementations correspond to the free modifiers expressed by adverbs, e.g. LOCATION, DIRECTION, TIME, MANNER. A nuclear TR does *not* contain complementations of anything else than the verb.

Essentially, there are two possibilities for the TFA of a nucleus TR, depending on whether the verb occurs as CB or NB, and therefore belongs to the topic or to the focus, respectively. These two possibilities are illustrated below [2]:

(1) [What can you tell me about the president?] He likes BROCOLI.
[[ACT:he^{cb}] ROOT:like^{nb} [PAT:brocoli^{nb}]]
λx. like(ACT:x,PAT:brocoli) {λQ. Q(ACT:he)}

(2) [What does the president like?] He likes BROCOLI.
[[ACT:he^{cb}] ROOT:like^{cb} [PAT:brocoli^{nb}]]
λQ. Q(PAT:brocoli) {λy. like(ACT:he,PAT:y)}

The TFA boundary thus always immediately precedes or follows the root-node.

Definition 1. λ-TR for a nucleus TR *The λ-TR corresponding to a TR τ has the form $F\{T\}$ where F stands for the Focus-part, and T stands for the Topic-part of τ. Given a nucleus TR τ containing the main-verb node, α, with $m+n$ nodes modifying it by dependency relations $D_1, \ldots D_{m+n}$, let us assume there are one or more CB complementation-nodes, $\beta_1, \ldots, \beta_m$ modifying α by dependency relations $D_1, \ldots D_m$, respectively , and one or more NB complementation-nodes, $\gamma_1, \ldots, \gamma_n$, modifying α by dependency relations $D_{m+1}, \ldots D_n$, respectively. Then the Topic part constituting the λ-TR is obtained by λ-abstracting over the NB nodes, and the Focus part is obtained by λ-abstracting over the CB nodes. The respective λ-expressions have the following shape:*

1. *iff the main-verb node is NB:*
   $T = \lambda Q.Q(D_1 : \beta_1, \ldots, D_m : \beta_m)$
   $F = \lambda X_1, \ldots \lambda X_m \alpha(D_1 : X_1, \ldots, D_m : X_m, D_{m+1} : \gamma_1, \ldots, D_{m+n} : \gamma_n)$
2. *iff the main-verb node is CB:*
   $T = \lambda X_1, \ldots \lambda X_n \alpha(Dep_1 : \beta_1, \ldots, Dep_m : \beta_m, D_{m+1} : X_1, \ldots, D_{m+n} : X_n)$
   $F = \lambda Q.Q(D_1 : \gamma_1, \ldots, D_m : \gamma_m)$

Special cases:

- *all complementation-nodes are NB ($m = 0$), and:*
  1. *the main-verb node, α, is also NB:*
     $T = \lambda Q.Q$
     $F = \alpha(D_1 : \gamma_1, \ldots, D_n : \gamma_n)$
  2. *the main-verb node, α, is CB:*
     $T = \lambda X_1, \ldots \lambda X_n \alpha(D_1 : X_1, \ldots, D_n : X_n)$
     $F = \lambda Q.Q(D_1 : \gamma_1, \ldots, D_m : \gamma_m)$
- *all complementation-nodes are CB ($n = 0$): the main-verb node, α, is the only NB node (because there must be at least one NB node in a well-formed TR), and the λ-TR has the following shape:*
  $T = \lambda Q.Q(D_1 : \beta_1, \ldots, D_m : \beta_m)$
  $F = \lambda X_1, \ldots \lambda X_m \alpha(D_1 : X_1, \ldots, D_m : X_m)$

Some Czech examples of λ-TRs with different structure are show below:[3]

[2] We use the usual typographical convention of depicting phonological focus by CAPITALS. It should be noted that we do no distinguish between different kinds of tunes, e.g. we do not have a special notation to mark constrast. Underlining depicts the items belonging to the focus-part of the utterance. We provide short questions to specify the intended context of use for a particular utterance. These questions should be seen along the lines of a question-test, rather than as in a question-answer pair in a dialogue.

[3] We use English equivalents of the Czech words in the λ-TRs for the sake of legibility for a reader unfamiliar with the Czech language.

(3) [Kdo dneska spálil topinku? (*En.* Who burned a/the toast today?)]
Dneska topinku spálil <u>JAN</u>. (*En.* <u>JOHN</u> burned the toast today.)
$\lambda Q.Q(ACT: john)\{\lambda X_1.burn(ACT: X_1, PAT: toast, TM: today)\}$

(4) [Co Jan dneska spálil? (*En.* What did John burn today?)]
Dneska spálil <u>TOPINKU</u>. [4] (*En.* He burned <u>the TOAST</u> today.)
$\lambda Q.Q(PAT: toast)\{\lambda X_2.burn(ACT: he, PAT: X_2, TM: today)\}$

(5) [Kdy Jan spálil topinku? (*En.* When did John burn a/the toast?)]
Jan topinku spálil <u>DNESKA</u>. (*En.* John burned the toast <u>the TODAY</u>.)
$\lambda Q.Q(TM: today)\{\lambda X_3.burn(ACT: john, PAT: toast, TM: X_3)\}$

(6) [Co se stalo s topinkou? (*En.* What happened to the toast?)]
<u>Jan</u> ji <u>SPÁLIL</u>. (*En.* <u>John BURNED</u> it.)
$\lambda X_2.burn(ACT: john, PAT: X_2)\{\lambda Q.Q(PAT: toast)\}$

(7) [Co Jan udělal? (*En.* What did John do?)]
Jan <u>spálil TOPINKU</u>. (*En.* John <u>burned a TOAST</u>.)
$\lambda X_1.burn(ACT: X_1, PAT: toast)\{\lambda Q.Q(ACT: john)\}$

5. From λ-TR to sentence-DRS

The first issue to be tackled when we want to construct a DRS corresponding to a given λ-TR is the assignment of discourse referents. We define a function, Θ, which transformes a λ-TR into a DRS. We use some of the formal machinery introduced for λ-DRT [Kuschert, 1995]: for merging DRSs, we employ the ⊗ operator, and for the construction of DRSs we employ the name- sensitive δ-abstraction operator which binds free variables across β-reduction and serves to declare discourse referents . We also employ the same linear notation for DRSs. We introduce the ⋈ operator which connects the λ-DRS corresponding to the topic of the sentence and the λ-DRS corresponding to its focus. This operator binds weaker than the λ-abstraction operator, the δ-abstraction operator and the merge operator, ⊗.

Definition 2. Transformation of a λ-TR into a DRS

Given a λ-TR of the form F{T} where F stands for the Focus-part, and T stands for the Topic-part, the λ-TR transformation function, Θ, is defined as follows:

1. $\Theta(F\{T\}) = \Theta(T) \bowtie \Theta(F)$
2. $\Theta(\lambda Q.Q(D_1 : \upsilon_1, \ldots, D_n : \upsilon_n)) =$
   $\lambda Q.(Q(D_1 : \upsilon'_1, \ldots, D_n : \upsilon'_n) \otimes \Gamma_1 \otimes \ldots \otimes \Gamma_n)$
3. $\Theta(\lambda X_1 \ldots \lambda X_m.\alpha(D_1 : \upsilon_1, \ldots, D_n : \upsilon_n)) =$
   $\lambda X_1 \ldots \lambda X_m.(\alpha(D_1 : \upsilon'_1, \ldots, D_n : \upsilon'_n) \otimes \Gamma_1 \otimes \ldots \otimes \Gamma_n)$

where

- $\upsilon'_i = r_x and K_i = \delta\{\}.T$ *iff* υ_i *is a pronoun*
- $\upsilon'_i = r_{k+1} and K_i = \delta\{r_{k+1}\}.r_{k+1} = r_x \wedge \upsilon_i(X_{k+1})$ *iff* υ_i *is a CB noun*
- $\upsilon'_i = r_{k+1} and K_i = \delta\{r_{k+1}\}.\upsilon_i(r_{k+1})$ *iff* υ_i *is an NB noun*
- $\upsilon'_i = \upsilon_i^{\prime}\Gamma_i = \delta\{\}.T$ *iff* υ_i *is an adverb*

The meaning of the symbols is as follows: K_j *is a λ-DRS, k is the index of the most recently declared discourse referent,* r_i *means the i-th discourse referent,* r_x *means an as yet undetermined discourse referent corresponding to the antecedent of an anaphoric expression,* υ.

The familiarity-novelty distinction in the declaration of discourse referents in 2 is oversimplified in that clauses (1) and (2) handle all pronouns and CB nouns

[4] Czech is a pro-drop language. We assume that the dropped Subject corresponding in this case to the Actor-slot of the verb in the Czech TR, is filled by some dummy symbol. The grammatical number and gender are carried by the verb. We treat the dummy symbol as a special kind of pronoun, as it can only occur in the Subject position.

as co-referential with some antecedent, and clause (3) handles all NB nouns as introducing a new discourse referent.

We show examples of applying Θ below:

(8) [Co se Janovi ráno stalo? (*En.* What happened this morning to Jan?)]

1. Jan ráno opékal CHLEBA. (*En.* Jan toasted BREAD.)
$\Theta(\lambda X_1.\lambda X_3.toast(ACT : X_1, PAT : bread, TM : X_3)\{\lambda Q.Q(TM : X_3)\}) =$
$\lambda Q.Q(ACT : r_1, TM : X_3) \otimes \delta\{r_1\}.r_1 = r_x \wedge jan(r_1) \bowtie$
$\lambda X_1.\lambda X_3 toast(ACT : X_1, PAT : r_2, TM : X_3) \otimes \otimes\delta\{r_2\}.bread(r_2)$
2. SPÁLIL ho. (*En.* He BURNT it.)
$\Theta(\lambda X_1.\lambda X_2.burn(ACT : X_1, PAT : X_2)\{\lambda Q.Q(ACT : he, PAT : it)\}) =$
$\lambda Q.Q(ACT : r_3, PAT : r_4) \otimes \delta\{\}.T \otimes \delta\{\}.T \bowtie \lambda X_1.\lambda X_2.burn(ACT : X_1, PAT : X_2)$
3. Spálil VAJÍČKA. (*En.* He burnt EGGS.)
$\Theta(\lambda Q.Q(PAT : eggs)\{\lambda X_2.burn(ACT : he)\}) =$
$\lambda X_2.burn(ACT : r_5) \otimes \delta\{\}.T \bowtie \lambda Q.Q(PAT : r_6) \otimes \delta\{r_6\}.eggs(r_6)$
4. Potom odešel rychle do PRÁCE.
(*En.* Afterwards he left for WORK quickly.)
$\Theta(\lambda X_1.\lambda X_4.leave(ACT : X_1, DIR : work, MNR : quickly, TM : X_4)\{\lambda Q.Q(ACT : he, TM : afterwards)\}) =$
$\lambda Q.Q(ACT : r_7, TM : afterwards) \otimes \delta\{\}.T \bowtie \lambda X_1.\lambda X_4.leave(ACT : X_1, DIR : r_8, MNR : quickly, TM : X_4) \otimes \delta\{r_8\}.work(r_8)$

6. Incremental discourse-DRS construction

Once a sentence-DRS has been constructed, it needs to be attached (in)to the discourse-DRS constructed so far. We define attachment to be sensitive to the topic-focus articulation of a sentence. Besides treating topic as a presupposed material, we employ the notion of *TF chaining*, which means that the topic part of a sentence is anchored to an accessible and suitable preceding topic, focus or an entire T-F nexus (or sequence thereof) [Korbayová and Kruijff]. Accessibility is the usual DRT notion defined in terms of DRS subordination.Suitability is defined in terms of unifiability of two λ-TRs. We take the whole λ-TRinto account when testing whether its topic-part can be anchored to something suitable in the preceding context, rather than unifying only the topic. The reason for this is that it enables us to test compatibility of the asserted information directly. A proper definition of attachment requires a formalization of a number of notions which needs more space then we have available in this abstract. The following is a sketch of the incremental construction of the DRS for (8), and its final result (though without additional contextual conditions obtained through anaphora resolution):

(8′) $(\lambda Q.Q(ACT : r_1, TM : X_3) \otimes \delta\{r_1\}.r_1 = r_x \wedge jan(r_1)) \bowtie$
$(\lambda X_1.\lambda X_3 toast(ACT : X_1, PAT : r_2, TM : X_3) \otimes \delta\{r_2\}.bread(r_2)) \otimes$
$(\lambda Q.Q(ACT : r_3, PAT : r_4) \otimes \delta\{\}.T \otimes \delta\{\}.T) \bowtie$
$(\lambda X_1.\lambda X_2.burn(ACT : X_1, PAT : X_2)) \otimes$
$(\lambda X_2.burn(ACT : r_5) \otimes \delta\{\}.T) \bowtie$
$(\lambda Q.Q(PAT : r_6) \otimes \delta\{r_6\}.eggs(r_6)) \otimes$
$(\lambda Q.Q(ACT : r_7, TM : afterwards) \otimes \delta\{\}.T) \bowtie$
$(\lambda X_1.\lambda X_4.leave(ACT : X_1, DIR : r_8, MNR : quickly, TM : X_4) \otimes$
$\delta\{r_8\}.work(r_8))$
$\longrightarrow^{+}_{\beta}$
$\delta\{r_1, r_2, r_6, r_8\}.r_1 = r_x \otimes$
$\lambda Q.Q(ACT : r_1, TM : X_3) \wedge jan(r_1) \bowtie$
$\lambda X_1.\lambda X_3 toast(ACT : X_1, PAT : r_2, TM : X_3) \wedge bread(r_2) \otimes$

$$\lambda Q.Q(ACT:r_1, PAT:r_2) \bowtie \lambda X_1.\lambda X_2.burn(ACT:X_1, PAT:X_2) \otimes$$
$$\lambda X_2.burn(ACT:r_1) \bowtie \lambda Q.Q(PAT:r_6) \wedge eggs(r_6) \otimes$$
$$\lambda Q.Q(ACT:r_1, TM:afterwards) \bowtie$$
$$\lambda X_1.\lambda X_4.leave(ACT:X_1, DIR:r_8, MNR:quickly, TM:X_4) \wedge work(r_8)$$

7. Concluding remarks

We present an approach incorporating the notion of information structure into the basic fragment of DRT. We employ the FGD view of information structure, referred to as topic-focus articulation, which is a dichotomy derived from the deep structure of the sentence. In this sense, our work implements ideas developed in the FGD framework. We represent the topic-part and the focus-part of a sentence by two related λ-terms which preserve the ingredients of the deep structure relevant for interpretation of the sentence with respect to the larger context. We present the essential ideas underlying the method of turning the λ-TR of a sentence into a DRS and incorporating it into the DRS representing the discourse in which the sentence occurs.

Including the TFA and the deep structure information, in particular dependency relations, in the DRS is useful for further discourse processing. For instance it enables a fine-grained account of coherence relationships which in turn facilitates the determination of discourse segments (in the sense of [Asher, 1993]. It also makes possible straightforward resolution of certain kinds of anaphora (using demonstrative pronouns).

Our approach easily extends to complex sentences composed of two or more subordinated or coordinated claues, which can be treated as each having their own "sub-TFA". Complex sentences can then be treated by decomposing them and relating their subparts by means of TF chaining, complemented by coherence relationships when required.

Since further elaboration of the formal apparatus sketched here and its employment in representing and interpreting discourses are subject of ongoing research, there are still many open questions and issues to be tackled. A profound comparison to the existing approaches with similar aims is therefore also under development.

References

[Asher, 1993] Asher, N. (1993). *Referring to Abstract Objects in Discourse*, volume 50 of *Studies in Linguistics and Philosophy*. Kluwer Academic Publishers, Dordrecht.

[Dekker and Hendriks, 1994] Dekker, P. and Hendriks, H. (1994). *Comments on "The Dynamics of Information Packaging"*. In Engdahl E., editor, *Integrating Infromation Structure into Constraint-based and Categorial Approaches*, pp. 27–38, Report of the DYANA-2 project, University of Amsterdam.

[Kamp and Reyle, 1993] Kamp, H. and Reyle, U. (1993). *From discourse to logic.* Kluwer Academic Publishers, Dordrecht, the Netherlands.

[Korbayová and Kruijff] Korbayová, I. and Kruijff, G.J.M. (1996). Identification of Topic-Focus Chains. In *Approaches to Discourse Anaphora: Proceedings of the Discourse Anaphora and Anaphora Resolution Colloquium (DAARC96).* Botley, S., Glass J. and McEnery, T. and Wilson, A. (eds.). University Centre for Computer Corpus Research on Language, University of Lancaster. Technical papers, No.8, pp.165–179.

[Kuschert, 1995] Kuschert, S. (1995). *Higher Order Dynamics: Relating Operational and Denotational Semantics for λ-DRT* Research Report, University of Saaarbruecken, Germany.

[Peregrin, 1995] Peregrin, J. (1995). Topic and focus in a formal framework. In Partee, B. H. and Sgall, P., editors, *Discourse and Meaning: Papers in Honor of Eva Hajičová.* John Benjamins, Amsterdam, The Netherlands.

[Sgall et al., 1986] Sgall, P., Hajičová, E., and Panevová, J. (1986). *The meaning of the sentence in its semantic and pragmatic aspects.* Reidel.

[Vallduví, 1994] Vallduví, E. (1994). *The Dynamics of Information Packaging.* In Engdahl E., editor, *Integrating Infromation Structure into Constraint-based and Categorial Approaches*, pp. 1-26, Report of the DYANA-2 project, University of Amsterdam.

Focus in complex noun phrases

Klaus von Heusinger, UCSC/Universität Konstanz

1. Introduction

Alternative Semantics (Rooth 1985, 1992) was developed to account for the phenomenon of association with focus as in (1) without moving the focused constituent $MARY_F$. The focused constituent rather supplies the adequate domain of quantification for the focus operator *only* by a recursive definition of the "alternative meaning" or "p-sets". However, Alternative Semantics, like other approaches to focus, does not treat definite and indefinite NPs, as in (2)-(6).

Intuitively the domain of quantification in (2) is similar to that one in (1), whereas the domain of quantification in (3) only includes professors. The latter example clearly indicates that it is not possible to analyze focus in complex NPs as focused complex NPs, as it might appear in (2). Krifka (1996, sect. 6) shows on examples like (4) that a movement approach to association with focus is not sufficient, since (4) cannot be paraphrased by "Mary is the only *y* such that Sam talked to the woman who introduced *y* to Sue" since the same woman might have introduced Bill to Sue, too.

(1) Sam only introduced MARY_F to John

(2) Sam only introduced the PROFESSOR_F to John

(3) Sam only introduced the DUTCH_F professor to John

(4) Sam only talked to the woman who introduced MARY_F to John

(5) Sam only talked to the woman who introduced the PROFESSOR_F to John

(6) Sam only talked to the woman who introduced the DUTCH_F professor to John

2. Alternative Semantics

Alternative Semantics (Rooth 1985, 1992) interprets the focus in situ and compositionally computes the alternatives that are generated by the focused expression at an additional semantic level. It distinguishes between two dimensions of meaning, the *ordinary meaning* $\| \|_O$ and the *alternative meaning* $\| \|_A$. The ordinary interpretation does not see the focus feature F and therefore interprets a focused expression like an unfocused one, as in (8a). The alternative interpretation of a focused expression creates the set of alternatives (or p-set), as in (8b), by the function ALT applied to the ordinary meaning, e.g. the alternative meaning of $MARY_F$ is the set of objects of the same type. The alternative semantics of an unfocused expression is the singleton containing the ordinary semantic value, as in (8c). The general schema (8) is instantiated for constants (i.e. proper names) in (9) and for intransitive verbs in (10).[1]

[1] I use an extensional semantics even though Rooth (1985) has shown that we need an intensional one. However, for the purpose of this paper the extensional semantics is sufficient.

(7) $\text{ALT}(\mathbf{d}) = D_{\text{type}(\mathbf{d})}$

(7a) $\text{ALT}(\|\text{Mary}\|) = D_{\text{type}(\|\text{Mary}\|)} = D_e = \{\mathbf{b}, \mathbf{j}, \mathbf{m}, ...\}$

(8a) $\|\alpha\|_O = \|\alpha_F\|_O$

(8b) $\|\alpha_F\|_A = \text{ALT}(\|\alpha\|_O) = D_{\text{type}(\|\alpha\|_O)}$

(8c) $\|\alpha\|_A = \{\|\alpha\|_O\}$

(9a) $\|c\|_O = \|c_F\|_O = \mathbf{c'} \in D_e$

(9b) $\|c_F\|_A = \text{ALT}(\mathbf{c'}) = D_e$

(9c) $\|c\|_A = \{\mathbf{c'}\}$

(10a) $\|V\|_O = \mathbf{V'} \in D_{<e,t>}$

(10b) $\|V_F\|_A = \text{ALT}(\mathbf{V'}) = D_{<e,t>}$

(10c) $\|V\|_A = \{\mathbf{V'}\}$

The alternative interpretation of functional application is the set formed by expressions that are derived from the application of an element *X* of the first alternative set to an element *Y* to the second alternative set. For instance, the alternative meaning of the application of a predicate to a focused argument is a set of objects (propositions, properties) that are formed by functional application of the (ordinary) meaning of the predicate to the elements of the alternative meaning of the argument, as illustrated in (12b).

(11a) $\|\alpha\ \beta\|_O = \|\alpha\|_O(\|\beta\|_O)$

(11b) $\|\alpha\ \beta\|_A = \{X(Y) | X \in \|\alpha\|_A, Y \in \|\beta\|_A\}$

(12a) $\|V(c)\|_O = \mathbf{V'}(\mathbf{c'})$

(12b) $\|V(c_F)\|_A = \{X(y) | X \in \|V\|_A, y \in \|c_F\|_A\}$

$= \{X(y) | X \in \{\mathbf{V'}\}\ y \in \text{ALT}(\mathbf{c'})\} = \{\mathbf{V'}(y) \mid y \in \text{ALT}(\mathbf{c'})\}$

The meaning of the focus sensitive operator *only* operates on both aspects of the meaning. When applied to a VP it yields two clauses: the first consists of the ordinary semantics and the second compares all alternatives with the ordinary meaning and asserts that there is no further alternative beyond the ordinary meaning. This is illustrated by the interpretation (14) of sentence (1).

(13) $\|\text{only VP}\|_O = \lambda x\ [\|\text{VP}\|_O(x)\ \&\ \forall P \in \|\text{VP}\|_A\ P(x) \rightarrow P = \|\text{VP}\|_O]]$

(14) $\|\text{Sam only introduced M}\text{ARY}_F \text{ to John}\|_O = \mathbf{introd'(m)(j)(s)}\ \&$

$\forall P \in \{\mathbf{introd'}(y)(\mathbf{j}) | y \in \text{ALT}(\mathbf{m})\}\ P(\mathbf{s}) \rightarrow P = \mathbf{introd'(m)(j)}]]$

The semantic definition of the alternative meaning of phrases in (8), of the functional application in (11) and the semantics of *only* in (13) determine the architecture of Alternative Semantics (Rooth 1985, 14; von Stechow 1991, 815; Krifka 1996, sect. 4).

3. N and N-modifier

In order to account for focus in complex NPs, I propose the following alternative interpretations of common nouns (N), restrictive adjectives (A) and restrictive relative clauses (RC). Semantically, they are all properties and have the same type as intransitive verbs, namely $<e,t>$. Thus, they receive the same ordinary and alternative semantic values as VPs. The ordinary semantic value is a set of individuals (i.e. a property) regardless whether the expression is focused or not. The alternative semantic value of a focused noun or adjective is the set consisting of alternative properties to the property expressed by the ordinary meaning. The alternative semantic value of an unfocused noun or adjective is the singleton consisting of the ordinary semantic value. Modification of a head noun α by an adjective β is interpreted in the ordinary semantics as the intersection of the ordinary semantic value of α with the ordinary semantic value of β. The alternative value of the modification is the set consisting of sets that are formed by intersection of an element R (i.e. set) of the alternative set of α with an element Q of the alternative set of β.[2]

(15a) $\|N\|_O = \|N_F\|_O = \mathbf{N'} \in D_{<e,t>}$ (16a) $\|A\|_O = \|A_F\|_O = \mathbf{A'} \in D_{<e,t>}$

(15b) $\|N_F\|_A = ALT(\|N\|_O) = D_{<e,t>}$ (16b) $|A_F\|_A = ALT(\|A_F\|_O) = D_{<e,t>}$

(15c) $\|N\|_A = \{\|N\|_O\}$ (16c) $\|A\|_A = \{\|A\|_O\}$

(17) $\|\alpha\ \beta\|_O = \{d|\ d \in (\|\alpha\|_O \cap \|\beta\|_O)\} = \|\alpha\|_O \cap \|\beta\|_O$

(18) $\|\alpha\ \beta\|_A = \{P|\ P = R \cap Q\ R \in \|\alpha\|_A\ Q \in \|\beta\|_A\}$

An N modified by a relative clause is interpreted according to the modification schemata given in (17) and (18). The relative clause RC is of type $<e,t>$, expressing a property, and can be instantiated either as an adjective (A) or as a predicate missing one argument (VP). The relative pronoun does not receive a semantic interpretation; it merely indicates which argument of the relative clause predicate is related to the head noun. The alternative interpretation generated by the modified N in (21) consists in combinations of properties expressed by the alternatives to the head noun and the alternative generated by the VP. It is a set of sets of individuals, as illustrated in (21a):

(19) $\|N \text{ who } RC\|_O = \{d|\ d \in \|N\|_O \cap \|RC\|_O\}$

(20) $\|N \text{ who } RC\|_A = \{P|\ P = a \cap b\ a \in \|N\|_A\ b \in \|RC\|_A\}$

---

2 Alternatively, N-modifiers can be described as functions from sets of individuals to sets of individuals, i.e. of type $<<e,t>,<e,t>>$. This semantic is equivalent to the one given in (17) and (18):

(17*) $\|\alpha\ \beta\|_O = \|\alpha\|_O(\|\beta\|_O) = \{d|\ d = f(e)\ f \in \|\alpha\|_O\ e \in |\beta\|_O\}$

(18*) $\|\alpha\ \beta\|_A = \{X(Y)|\ X \in \|\alpha\|_A, Y \in \|\beta\|_A\} = \{P \mid P = R(S)\ R \in \|\alpha\|_A\ S \in \|\beta\|_A\}$

(21) $\|$woman who introduced MARY$_F$ to John$\|_A$

= {P| P = a ∩ b a∈ $\|$woman $\|_A$ b∈ $\|$introduced MARY$_F$ to John$\|_A$}

= {P| P = a ∩ b a∈ {**woman'**} b∈ {**introd'**(z)(**j**)| z ∈ ALT(**m**)}}

= {P| P = λx [**woman'**(x) & **introd'**(z)(**j**)(x)] z ∈ ALT(**m**)}}

(21a) e.g. {{**Mary'**, **Sue'**}, {**Sue'**, **Ana'**, **Dora'**}, {**Mary'**, **Karla'**}, ...}

4. Determiners

At the international faculty party, some students, several German, Italian and American professors, but only one Dutch professor appeared. In this context, sentence (3), repeated as (22), can be felicitously uttered. The domain of quantification includes all professors at the party. Although the ordinary meaning (22a) can be described with the iota operator indicating some uniqueness conditions, this semantics cannot be transferred to the alternative meaning, since it would counter intuitively restrict the domain of quantification to only those professors that are unique with respect to their nationality, as indicated in (22b). The alternative function of the definite article is rather to collect all individuals from all alternatives to the property expressed in the modified noun as indicated in (22c), and more general in (23).

(22) Sam only introduced the DUTCH$_F$ professor to John

(22a) $\|$the DUTCH$_F$ professor$\|_O$ = ιx [**Dutch'**(x) & **prof'**(x)]

(22b) $\|$the DUTCH$_F$ professor$\|_A$ = {d| d = ιx [Rx & **prof'**(x)] for all R ∈ $\|$DUTCH$_F$ $\|_A$} = {ιx [**Dutch'**(x) & **prof'**(x)], ιx [**Germ'**(x) & **prof'**(x)], ιx [**Ital'**(x) & **prof'**(x)]...}

(22c) $\|$the DUTCH$_F$ professor$\|_A$ = {d| d∈ R for all R ∈ $\|$DUTCH$_F$ professor$\|_A$}

= {d| d∈ R for all R ∈ {λx [**Dutch'**(x) & **prof'**(x)], λx [**Germ'**(x) & **prof'**(x)], λx [**Ital'**(x) & **prof'**(x)], ...}

(23) $\|$the N$\|_A$ = {d| d∈ R for all R ∈ $\|$N$\|_A$}

Example (4), repeated as (24), served as the key argument for Krifka (1996) to introduce his "hybrid" approach to focus, combining elements of movement theories and Alternative Semantics. However, the example can be solved by using only Alternative Semantics extended in the above demonstrated way. The alternative meaning of the complex N was already computed in (21); it is a set of sets of individuals. The alternative function of the article is to transform this into a set of individuals as illustrated in (24a). This combines with the matrix sentence yielding the meaning of the whole sentence in (24b):

(24) Sam only talked to the woman who introduced MARY$_F$ to John

(24a) $\|$the woman who introduced MARY$_F$ to John$\|_A$

$= \{d| d\in R$ for all $R \in \|$woman who introduced MARY$_F$ to John$\|_A\}$

$= \{d| [\textbf{woman'}(d)\ \&\ \textbf{introd'}(z)(\textbf{j})(d)]\ z \in ALT(\textbf{m})\}$

$= \{d| \exists z\ [\textbf{woman'}(d)\ \&\ \textbf{introd'}(z)(\textbf{j})(d)]\}$

(24b) $\|$Sam only talked to the woman who introduced MARY$_F$ to John$\|_O$ = $[\textbf{talk'}(\iota x\ [\textbf{woman}(x)\ \&\ \textbf{introd'}(\textbf{m})(\textbf{j})(x)](s)\ \&\ \forall P \in \{\textbf{talk'}(y) \mid y \in \{d| \exists z\ [\textbf{woman'}(d)\ \&\ \textbf{introd'}(z)(\textbf{j})(d)]\}\}\ P(s) \rightarrow P = \textbf{talk'}(\iota x\ [\textbf{woman}(x)\ \&\ \textbf{introd'}(\textbf{m})(\textbf{j})(x))]$

5. Determiners and the Architecture of Alternative Semantics

Let us assume that the ordinary meaning (25) of the definite article is a function of type *<<e,t>,e>*, i.e. a function that assigns one element to a set. If we furthermore assume, following the general principle (8c), that the alternative meaning of an unfocused expression is the singleton set of its ordinary meaning, as in (26), then we must postulate a very unnatural alternative meaning for the complex noun *N* in (27). The alternative meaning of the complex noun must include singleton sets of all possible alternative individuals in order to allow the determiner to collect all alternative individuals. In such a case the determiner would assign to each singleton its element and fail to assign an element to any other set. We have already seen in (22b) that this application is highly artificial.

(25) $\|$the$\|_O = f_{<<e,t>,e>}$

(26) $\|$the$\|_A = \{f_{<<e,t>,e>}\}$

(27) $\|$the N$\|_A = \{X(Y)| X\in \{f_{<<e,t>,e>}\}, Y\in \|N\|_A\}$

$= \{d| d = f_{<<e,t>,e>}(Y)$ for all $Y\in \|N\|_A\}$

Alternatively, I propose a more direct analysis of complex NPs in Alternative Semantics. The definite article is assigned an alternative function of type *<<e,t>,t>,<e,t>>*, as in (28), which was derived from the discussion in the last section. The alternative meaning of the functional application of the article to a complex noun consists in the direct application of the alternative function to the alternative meaning of the N in (29), rather than the complex application in (27).

At a more abstract level, one could merge the ordinary and the alternative function into one: The meaning of the article could be described, as in (30), by a function *f* that takes a set of type *<τ,t>*, and yields one of its elements of type *τ*. In this view, the article stands for a polymorph choice function or a general "type shifter". In the ordinary interpretation, the definite article takes a singleton and yields its unique element, whereas in the alternative interpretation it takes a set of sets and yields the largest set in that set (assuming some maximality condition).

(28) $\|$the$\|_A = f_{<<e,t>,t>,<e,t>>}$

(29) $\|$the N$\|_A = f_{<<e,t>,t>,<e,t>>}(\|N\|_A) = s_{<e,t>}$

(30) $\|$the$\| = f_{<<\tau,t>,\tau>}$

The final question is why does the alternative meaning of the article differ from the alternative meanings of other expressions and why does it not follow the general principles of Alternative Semantics described in (8) and (11). There are two suggestion: First, these principles were designed for content words, which contribute to the focus-background structure, but not for function words like the article, which do not contribute to this structure. Second, the article cannot be focused itself - perhaps it is "invisible" for the recursive definition of the alternative meaning. Both suggestion motivate investigation into other functions words. In fact, the indefinite article behaves quite similar to the definite one. The alternative meaning of indefinite complex NPs are identical with the one for definite one. The domain of quantification for *only* in (31) is the same as in (22). This can only be explained if we assume the same alternative function for definite and indefinite articles.

(31) Sam only introduced a DUTCH$_F$ professor to John

6. Conclusion

Alternative Semantics can be extended to analyze focus in complex noun phrases. However, the alternative meaning of the article cannot be derived in the same way as the alternative meaning of content words. This indicates that the main rules (8) and (11) of Alternative Semantics cannot be applied to determiners. Finally, it was noted that the definite and indefinite article have the same alternative meaning. This might reflect common aspects of their ordinary meaning.

References

Krifka, Manfred 1996. Frameworks of the Representation of Focus. ESSLI 96 Conference on Formal Grammar.

Rooth, Mats 1985 Association with Focus. Ph.D. Dissertation at University of Massachusetts, Amherst 1985. Graduate Linguistics Student Association (GLSA): University of Massachusetts, Amherst.

Rooth, Mats 1992. A Theory of Focus Interpretation. Natural Language Semantics 1, 75-116.

von Stechow, Arnim 1991. Current Issues in the Theory of Focus. In: A. von Stechow & D. Wunderlich (eds.). Semantik. Ein internationales Handbuch der zeitgenössischen Forschung. Berlin: de Gruyter, 804-825.

Accent Interpretation, Anaphora Resolution and Implicature Derivation

Paul Piwek[1]
IPO, *Eindhoven*

Introduction

In many textbooks on logic which have been written in this century (e.g., Copi, 1972), there is a section dealing with the fallacies. It is customary that such a section contains a few lines on accent[2] stating that accent is a source of fallacious reasoning. This claim is then supported by the observation that accent influences the meaning of a sentence. Take the injunction in (1).

(1) We should not speak ill of our friends.

Normally, (1) is not intended to incite the listener to speak ill of those people who are not his or her friends. An accent on 'our friends' does, however, change the meaning of the sentence in this direction. In the aforementioned textbooks, a remark on accent such as this one is usually presented as part of a discussion on informal logic which which bears little or no relation to the material on formal propositional and predicate logic in the same book. This situation is owing to the fact that differences in meaning related to accent have for a long time resisted formalization.

Since the inception of Discourse Representation Theory (DRT; Kamp, 1981; Kamp & Reyle, 1993), the situation has changed. DRT provides a formal basis for dealing with the meaning of accent. Here I want to mention two contributions which exemplify the advances that have been made in this area.

Firstly, there is Van Deemter (1994a), which deals with the influence of accent on *anaphora resolution*. Consider (2), where accent is indicated with italics.

(2) a. John fed the animals. The cats were hungry.

b. John fed the animals. *The cats* were hungry.

Before presenting Van Deemter's analysis, let us introduce the following abbreviation: if e is an anaphoric expression, then $\mathcal{R}(e)$ stands for the (discourse) referent of e. Roughly speaking, (2.a) corresponds to a reading where $\mathcal{R}$(the cats) = $\mathcal{R}$(the animals), i.e., the referents coincide, whereas (2.b) reads $\mathcal{R}$(*the cats*) $\subset$ $\mathcal{R}$(the animals). Van Deemter explains these observations by positing that accent on an anaphoric expression indicates a non-identity anaphor.[3]

Secondly, there is Rooth (1992), which contains a formalization of the idea that accent induces *contrast between alternatives*. Imagine that the following conversation takes place after an exam which Mats, Steve and Paul took.

(3) George: How did it go?
Mats: Well, *I* passed.

[1]Thanks are due to Kees van Deemter, Emiel Krahmer, and the participants of the 'Information Packaging' seminar at IPO and the 'Questions under Discussion' workshop in Amsterdam for discussion and comments.

[2]We take (pitch) accent (also referred to as *intonational focus*) to be the highlighting of an expression by prosodic means. Differences in accent type are not dealt with in this paper.

[3]Note that Van Deemter's approach employs standard DRT. In this respect, it differs from, for instance, Vallduví (1992). Vallduví uses Heim (1982)'s file cards instead of Kamp's DRSs to account for the meaning of accent. The former contain more structure. Hendriks & Dekker (1995) show that such additional structure is superfluous.

In this situation, George seems licensed to infer that Steve and Paul did not pass the test. Rooth explains this by associating sentences with a so-called focus semantic value in addition to the ordinary semantic value (which is the proposition expressed by the sentence). In this case, the focus semantic value corresponds to the set of propositions of the form x passed (i.e., the alternatives to the proposition that the speaker actually expressed). The inference that Steve and Paul did not pass is now explainable using the Gricean quantity implicature (Grice, 1975). The idea is that there is a scale on the set of propositions x passed. By asserting the proposition 'Mats passed', Mats denies all propositions which are higher on this scale (i.e, the stronger propositions 'Mats and Steve passed', 'Mats and Paul passed', 'Mats, Paul, and Steve passed'). Rooth applies his theory to several other empirical domains (such as focusing adverbs and bare remnant ellipsis) which are beyond the scope of this paper.

The theories of Van Deemter (1994a) and Rooth (1992) account for different data. It is not immediately obvious whether there exists one theory which covers all the data. We think that one aspect of Rooth's theory that we did not yet discuss provides a starting point for such a theory. Consider:

(4) An *American* farmer met a *Canadian* farmer.

Rooth notes that the relation between the ordinary semantic value of '*American* farmer' and '*Canadian* farmer' (and vice versa) is subject to the constraints which also apply to presuppositions. More specifically, according to his theory the ordinary semantic value of the one should be a member/subset of the focus semantic value of the other (e.g., $\lambda x(\text{american}(x) \wedge \text{farmer}(x)) \in \lambda x(\text{P}(x) \wedge \text{farmer}(x))$).

In this paper, we take a more radical stance: we assume that an accent on definites and indefinites induces a genuine 'alternative' presupposition.[4] For instance, 'The *american* farmer' is associated with the following two presuppositional boxes:[5] $[x \mid \text{american}(x), \text{farmer}(x)]$ and the alternative presupposition $[x \mid \text{farmer}(x)]$. Both presuppositions behave as described in Van der Sandt (1992): they can be bound or accommodated. We propose two conditions on the relation between alternative and actual referents of accented (in)definites. The conditions are motivated by the contrastive function of accenting.

In the next section, the details of our proposal are spelled out. In the final section, we describe the differences with the theories of Van Deemter (1994a,b) and Rooth (1992). We conclude that our proposal covers both the non-identity anaphora and contrastive configurations data using DRT.

The Proposal

Before we present the core of our proposal, let us first sketch how presuppositions can be dealt with in DRT. We assume that the reader is already familiar with DRT itself.

PRESUPPOSITIONS In Van der Sandt (1992), presuppositions (which are triggered by, for instance, definites such as 'the car') are dealt with like anaphoric pronouns in DRT. Consider (5.a) and the corresponding (somewhat simplified) unresolved Discourse Representation Structure (DRS) in (5.b).

(5) a. If John buys a Ferrari, the car must be cheap.

b. $[\mid [x \mid \text{Ferrari}(x), \text{buy\_john}(x)] \Rightarrow [\mid \text{cheap}(y)[y \mid \text{car}(y)]]]$

[4] We think that our account can be extended to other quantifiers. They are, however, beyond the scope of this paper.

[5] The notion of a presuppositional box comes from Van der Sandt (1992).

The presupposition trigger 'the car' has introduced a so-called presuppositional box ($[y \mid \text{car}(y)]$) into the consequent of the DRS. The idea is that this presuppositional box needs to be resolved, i.e., bound by a suitable and accessible antecedent. Given the background knowledge that Ferraris are cars, the x is such an antecedent. The resolved representation of the sentence is obtained by substituting x for y and removing the presuppositional box (the result can be paraphrased as 'If John buys a Ferrari, it must be cheap'):

(6) $[\mid [x \mid \text{Ferrari}(x), \text{buy\_john}(x)] \Rightarrow [\mid \text{cheap}(x)]]$

Alternatively, if no suitable and accessible antecedent is available, the presuppositional box can be added to the main DRS or a subordinate DRS on the path between the source of the presupposition and the main DRS. This is known as *accommodation*.

Whether a discourse referent is a suitable antecedent depends on many factors. Here we will consider only one constraint which is required further on in this paper.

We assume that discourse referents can stand both for individuals and sets of individuals (e.g., *john* vs. *the cats*). Some of the aforementioned referents will be literal members of the main DRS, whereas others can be obtained from the explicitly present referents via function application. Generally speaking, there will be functions which relate one set/individual to another associated set/individual. For instance, *children* could be a function which when applied to an individual, returns the set of all her/his children. Similarly, *daughters* would return the set of all daughters of the person in question. Furthermore, it will be useful to have functions which given a set S, return a set S' such $S' \subset S$.

Now consider the following discourse, and in particular the presupposition trigger 'His children':

(7) John is a nice guy. His children are just like him.

Suppose, that the set of John's children is not explicitly present in the main DRS. The hearer has to find a set of individuals associated with John, such that for each of the individuals it holds that it is child of John. Amongst the possible candidates are the set of all of John's children, but also all its non-empty subsets. We have to ensure that 'his children' selects the set containing all of John's children (since this seems to be the natural reading of (7)). The following condition accomplishes this (*cf.* Van Eijck, 1983):

(C0) Maximality Condition *Only sets which are maximal with respect to the descriptive content of a presupposition trigger can fill the gap introduced by the presupposition. A set S is maximal with respect some descriptive content D, if it holds that* $\forall x \in S : D(x) \wedge \neg(\exists S' : S \subset S' \wedge \forall x \in S' : D(x))$.

We have considered the construction of new referents out of explicit referents. Needless to say that this procedure can be iterated. We do, however, assume that the more steps it takes to arrive at a referent, the less accessible it becomes. In Discourse Representation Theory, a referent is either accessible or not, depending on its relative position in the DRS. Ariel (1990), amongst others, discusses *accessibility degrees* which referents can have. The degree of accessibility is influenced by factors such as the distance between anaphor and antecedent, the fact whether an object is the discourse topic, parallelism, plausibility, etc.

ALTERNATIVE PRESUPPOSITIONS We start from the assumption that accent is a means for indicating contrast. We understand contrast in discourse as *binary*: one discourse referent is contrasted with another discourse referent. Furthermore, we contend that only distinct discourse referents can be contrasted with each other. Distinctness is defined as follows:

(D0) Distinctness *Two referents a and b are* distinct $\Leftrightarrow$ **(1)** *If a and b are sets, then* $a \cap b = \emptyset$; **(2)** *If a and b are individuals, then* $a \neq b$; **(3)** *If a is an individual and b a set, then* $\neg(a \in b)$.

In case of an accented (in)definite, a contrast is induced between the actual referent of the (in)definite, and the referent of the alternative presupposition. The alternative presupposition is computed by removing all conditions in the actual presupposition which descended from accented material. For example, the alternative presupposition of 'The *cats*' corresponds to $[x \,|\,]$, which is computed by erasing $\mathrm{cat}(x)$ from the representation of the actual presupposition: $[x \,|\, \mathrm{cat}(x)]$ (in this case, the presuppositional box is technically the same as that of a pronoun).

There are two conditions which an actual referent and its alternative referent have to satisfy. Firstly, they should be distinct:

(C1) Distinct Referents Condition *For an actual referent a and the corresponding alternative referent b, it holds that a and b are distinct.*

Secondly, the discourse referent of the alternative presupposition should be equally or more accessible than the actual referent of the (in)definite.

(C2) Marked Accessibility Condition *If a is the actual referent and b the corresponding alternative referent, then: acc(a)* $\leq$ *acc(b) (where acc stands for accessibility of).*

The idea behind (C2) is that accenting an expression puts it in opposition to its unaccented (unmarked) variant. An accent which marks an expression signals that the meaning of the expression is also marked. For an anaphoric expression, marking guides the hearer to the marked (less accessible) referent.

Let us now reconsider example (2.b). Assume that a is the (set) referent introduced by the definite 'the animals'. We are now going to examine the possibilities concerning the identity of the actual referent c of *the cats* and the alternative referent o.

1.	$a \cap c = \emptyset$: c has to be accommodated.	
2.	$a = c$	(i) $o \subset a$, $o = a$, $a \subset o$ or $a \cap o \neq \emptyset$: violation of C1.
		(ii) $a \cap o = \emptyset$: accommodation of o: violation of C2.
3.	$a \subset c$	(i) $o \subset a$, $o = a$, $a \subset o$ or $a \cap o \neq \emptyset$: violation of C1.
		(ii) $a \cap o = \emptyset$: accommodation of o: violation of C2.
4.	$c \subset a$	result: by (C2) $o \subset a$; by (C0) $a = c \cup o$; by (C1) $a \cap o = \emptyset$.
5.	$a \cap c \neq \emptyset$ (and not 2.,3. or 4.): violation of C0.	

Only the possibilities 1. and 4. satisfy all the conditions. Solution 1. yields a reading where '*the cats*' are distinct from 'the animals'. Solution 4. gives us the subset reading: '*the cats*' are a subset of 'the animals'. In this case, the interaction between the conditions C0, C1, and C2. ensures that the set of animals is 'split up' between c and o.

Note that 2(ii) and 3(ii) are ruled out by condition C2: one cannot contrast a referent with a referent which has to be accommodated, because such a referent is not accessible.[6]

[6]There is a hedge: a referent may be accommodated and later get more specified, as in '*John* liked her. *Peter* didn't.', where $\mathcal{R}(Peter)$ can bind the alternative presupposition of '*John*').

We have illustrated how our proposal accounts for the interaction between accent and anaphora resolution. Let us now turn to implicature derivation. The idea is very simple: the implicature is the *denial* of the asserted proposition in which the alternative referent has been substituted for the actual referent.[7]

For (2.b), we compute on the basis of *the cats (amongst the animals) are hungry* the implicature that *the other animals are not hungry*. Of course, implicatures are defeasible. If subsequently, the speaker says '*The dogs* were, too', the aforementioned implicature is cancelled. For example (3), we get that *Steve and Paul did not pass*. We assume that the accent on '*I*' introduces an alternative referent for of the other relevant individuals at that point in the conversation (in this case, Steve and Paul).

Comparisons

Let us first compare our proposals with Van Deemter's non-identity account and a related account presented in Hendriks & Dekker (1995). Consider the following example.

(8) The children and their parents went to the fair. *The children* enjoyed it.

Note that the accent on '*the children*' seems at first sight not explainable in terms of non-identity anaphora, since a referent for the children is introduced in the first sentence of (8). One could, however, argue that there is a non-identity anaphor anyway, because we should think of 'The children and their parents' as introducing one referent.[8] But now consider:

(9) The children and their parents went to the fair. The *small* children enjoyed it.

How is it possible that 'children' receives no accent in the second sentence. Van Deemter (personal communication) argues that this is due to the concept givenness of 'children'. But then again, '*children*' is also concept given in (8). Van Deemter (personal communication) argues that this might mean that the examples need a different analysis in the spirit of (Van Deemter, 1994b) which deals with contrast in terms of contrariety. This means that we need to abandon the idea of a unitary explanation for the relatively similar examples (2), (8) and (9). Thus Hendriks & Dekker (1995)'s claim that they provide a theory which covers both the data on anaphora resolution and contrast becomes problematic. Note that for our approach, the examples present no problem. For (8), there is an alternative presupposition which can be bound by $\mathcal{R}$(The parents), and for (9), there is an alternative presupposition which can be bound by a set consisting of the children that are not small (the implicature is that these children did not enjoy the visit to the fair).

Furthermore, we would like to compare Van Deemter (1994b)'s treatment of contrastive accent with ours. Consider the following example from Van Deemter (1994b):

(10) *John* is married to *Mary* and *Peter* is married to *Sally*.

[7] In case of multiple accents within an assertion, we obtain a set of implicatures, by following the aforementioned rule for each accented position separately. Furthermore, we assume that the denial of an assertion involving a distributive predicate distributes over the members of the set type arguments: the denial of $P(a)$, where P is a distributive predicate, corresponds to $\forall x \in a : \neg P(a)$. In this paper, there is no room to go into some refinements which are needed to predict the correct implicatures for accented indefinites.

[8] Van Deemter and Hendriks (personal communication) tend towards this solution.

Van Deemter proposes that contrast is licensed by contrariety between the conjuncts (possibly with substitutions of arbitrary variables for corresponding accented positions). Since there is no direct contrariety between 'a is married to *Mary*' and 'a is married to *Sally*', Van Deemter assumes that an implicature might be generated that the sentence is uttered in a monogamous society, thus obtaining a contrariety after all. We think, however, that even in a non-monogamous society we get the implicatures that John is not married to Sally and Peter is not married to Mary (which follow directly from our account). It is impossible to get these directly via Van Deemter's proposal: if there is no direct contrariety, he is always forced to assume that an interpreter 'accommodates' some 'rule' (i.e., 'monogamy': 'if a is married b and $c \neq b$, then a is not married c') which enables the derivation of a contrariety. It is not clear what 'rule' an interpreter would need to come up if she or he knows that the society in question tolerates polygamy.

Finally, let us discuss the relation of our proposal to Rooth's alternative semantics. Our proposal can be seen as an amendment of the latter. In particular, we propose that accent induces an alternative presupposition which seeks a referent of the same type as the actual referent of the accented definite or indefinite. Note that according to Rooth (1992, fn. 8) an accented adverb yields a discourse referent of property type, whereas the referent of the indefinite in which the adverb occurs is of individual type. Because in our proposal the actual and alternative referent are of the same type, we can account for the interactions between presuppositions and accents via the conditions (C1) and (C2). Note that instead of Rooth's alternative semantic values we use DRSs together with presuppositional boxes. The latter are removed from the semantic representation of the utterance during the interpretation process.

It is only fair to say that Rooth's theory accounts for many more phenomena which were not dealt with in this paper. It is an open question whether the proposal covers all the other empirical domains dealt with in Rooth (1992).

References

- Ariel, M. (1990), *Accessing Noun-Phrase Antecedents*, Routledge, London and New York.
- Copi, I.M. (1972), *Introduction to Logic*, MacMillan, New York.
- Van Deemter, C. (1994a), 'What's New? A Semantic Perspective on Sentence Accent', *Journal of Semantics*, 11, 1–31.
- Van Deemter, C. (1994b), 'Contrastive Stress, Contrariety and Focus', In: P. Bosch & R. van der Sandt (eds.), *Focus and Natural Language Processing*, Working papers 6 of the IBM Institute for Logic and Linguistics, Heidelberg.
- Grice, H.P. (1975), 'Logic and Conversation', In: P. Cole & J. Morgan (eds.) *Speech Acts. Syntax and semantics, Vol. 11.*, Academic Press, New York.
- Van Eijck, J. (1983), 'Discourse Representation Theory and Plurality', In: A. ter Meulen (ed.), *Studies in Modeltheoretic Semantics*, Foris, Dordrecht, 85–106.
- Heim, I. (1982), *On the Semantics of Definite and Indefinite Noun Phrases*, PhD dissertation, University of Amherst.
- Hendriks, H. & P. Dekker (1995), 'Links without Locations: Information Packaging and Non-Monotone Anaphora', In: Dekker, P. & M. Stokhof (eds.), *Proceedings of the 10th Amsterdam Colloquium*, part II, University of Amsterdam, Amsterdam, 339–358.
- Kamp, H. (1981), 'A Theory of Truth and Semantic Interpretation', In: Groenendijk, J., T. Janssen & M. Stokhof (eds.), *Formal Methods in Study of Language*, Mathematical Centre Tracts 136, Amsterdam, 277-322.
- Kamp, H. & Reyle, U. (1993), *From Discourse to Logic*, Kluwer Academic Publishers, Dordrecht.
- Rooth, M. (1992), 'A Theory of Focus Interpretation', *Natural Language Semantics*, 1, 75–116.
- Van der Sandt, R. (1992), 'Presupposition Projection as Anaphora Resolution', *Journal of Semantics*, 9, 333–377.
- Vallduví, E. (1992), *The informational component*, Garland, New York.

The Context-dependence of Questions and Answers*

Robert van Rooy
University of Amsterdam

The *appropriateness* and *content* of questions and answers depends on context. In this paper a dynamic semantics is formulated in which contexts contain enough information about the discourse to determine what is expressed by questions and answers, and enough information about what is presupposed about the subject matter of conversation to determine their appropriateness. It is proposed that *mention-all* and *mention-some* questions introduce not only *partitions* to the context, but also that they make the context-dependent *abstracts* that underlies these partitions anaphorically accessible. The latter information about the discourse is needed to determine what is expressed by an answer. These abstracts are also used to determine the (default) exhaustive interpretation of *focused* constituents, and the (default) non-exhaustive interpretation of *topical* constituents.

In Rooth's (1985, 1992) semantic theory of focus, sentences in which focused constituents occur are always interpreted relative to a set of alternatives. For bare focus constructions, this alternative set is used to determine the *appropriateness* conditions of the sentence with the focal constituent, while for cases where the sentence contains a focus sensitive operator like *only*, this alternative set can even be used to determine the *truth conditions* of the sentence. Von Stechow (1989) has argued, however, that the two-dimensional account of Rooth is not flexible enough, because it is not able to determine the right truth conditions of sentence (b) *John introduced only Bill to Mary* in the context of the question (a) *Which gentlemen did John already introduce to which of their diner partners?*[1] The theory of Rooth (1985) falsely predicts that (b) is false if John already introduced the gentlemen of the diner to each other, but has only started introducing the gentlemen to their diner partners. The reason for the false prediction is that in Rooth (1985) the quantification involved by *only* is only sensitive to the alternatives determined by the *focus value* of the sentence, and that this focus value is determined in a *context-independent* way. Rooth (1992) responded by saying that the focus-value of a sentence only puts constraints on the domain of quantification of *only*, but need not determine it. How this domain of quantification is determined is left to pragmatics.

In traditional pragmatic theories the notion of context plays two roles: (i) it should contain enough information about the conversational situation to determine what is expressed by a context dependent utterance, and (ii) it should contain enough information about what the participants of the conversation commonly assume about the subject matter of the conversation to determine whether what is said by a speaker is appropriate or not. The central idea behind recent theories of discourse is that there is a single notion of context that plays both of these two roles, and that both kinds of information modelled by this single context change during a conversation in an interactive way.

For the analysis of questions and answers too there is a single notion of context that should play both of those two roles. First, a context should contain enough information about the discourse to determine what is expressed by a question in which a context dependent expression occurs, and to determine the truth-conditions of what is expressed by an answer. The point is that the latter can normally not be determined without knowing which question the answer is supposed to answer. Second, a context should contain enough information about the subject matter of conversation to determine whether a question can be appropriately asked, and whether a certain answer is a partial or a complete answer to a question. For instance, to ask a question is not appropriate in a certain context if its (complete) answer is already entailed by the context. But obviously, the two kinds of information should not be separated, because to be able to determine whether a certain answer is partial or complete relative to a question, a context should also represent certain information about the discourse, namely what questions are asked.

A question can be anaphorically dependent on foregoing discourse because it can contain an explicit pronoun, as when A says *I bought a car* and Q responds by asking *How much did it cost?* More interesting, however, is that what is expressed by a wh-question is normally context-dependent in the sense that in different contexts the domain over which the values of a wh-phrase vary might be different. Just as what is expressed by the assertion *Everybody went to the concert* depends on the contextually given domain of quantification,

* I would like to thank Chris Albert and Ede Zimmermann.

[1] The example and argument are attributed to Ede Zimmermann.

so does what is expressed by the question *Who went to the concert?* depend on a contextually given domain. It seems reasonable to assume that domain restriction for questions should be accounted for in a similar way as domain restriction for quantification, namely by anaphoric means.

Answers are normally elliptical in form and what is expressed by an answer is normally partially determined by the question. If answers are treated as elliptical sentences that are completed via the question, it seems natural to assume that the domain of quantification of *only* in a sentence like *Only John is wise* is somehow given by the question it answers.

In an interesting article Jäger (1996) goes some way of accounting for this domain restriction in a very systematic way. For instance, he can account for the fact why the assertion *Only Leibniz is wise* only makes a claim about German Philosophers in the context of the question *Which German philosophers are wise?* if nobody's wisdom is yet presupposed. Unfortunately the account fails if it is already presupposed that Descartes, for instance, is wise, or when it is presupposed that Descartes is wise iff Leibniz is wise. In that case Jäger (1996) wrongly predicts that the above assertion is false in the context of the above question.

Jäger's (1996) account of domain restriction is based on Groenendijk and Stokhof's (1984) theory of questions. The latter authors argue that the general theory of questions should be a propositional one, where the intension of a question is a set of mutually exclusive propositions thought of as the set of all alternative complete exhaustive answers to the question, and its extension an element of this set: its actual complete exhaustive answer, a proposition. Their treatment is very general in that yes-no questions, normal wh-questions, and multiple wh-questions all have denotations in the same category. On the basis of this uniform treatment they can give a general characterisation of the notion of answerhood and of the notion of question. In particular, it allows them to give a general definition of entailment between all kinds of interrogatives simply by inclusion of denotation (intension). Assuming that the extension of a question is a proposition, Groenendijk & Stokhof (1984) can also straightforwardly explain why questions can freely be conjoined with declaratives when embedded under verbs like *know*. In particular, to account for wh-complements like *John knows who came to the party*, they don't need to postulate two separate verbs of knowledge, as Karttunen (1977) did.

There seems to be a natural way to implement their approach towards questions in a dynamic framework: assume that information states should be modelled in terms of partitioned structures where each cell of the partition represents the complete answer to a question relevant in the discourse. According to this modelling, answers eliminate cells of an existing partition, while questions partition the context in a more fine grained way, and thus introduce partitions.

Tempting as this idea is, already from the work of Groenendijk & Stokhof (1984, pp. 278-283) it is clear that this won't quite work. To account for the question-answer relation, that is, to determine what is expressed by an answer, they make essential use of so-called *abstracts*. The chosen abstract needed to determine what is expressed by the answer is the abstract that underlies the partition induced by the question. Interestingly enough, these abstracts express properties or relations. What is crucial is that the abstracts underlying the partitions contain more information than the partitions themselves. For instance, as first observed by Zimmermann (1985), although the abstracts associated with *Who walks?* and *Who doesn't walk?* are distinct, the partitions induced by these abstracts are the same. But how can it then be explained that the constituent answer *John and Mary* would express a different proposition if answered to the first or to the second question? My conclusion is that to account for answers in a dynamic framework we need to be able to refer back to something like the abstract associated with the question the answer answers. It is this information about the discourse that is needed to determine what is expressed by an answer.

Some of these abstracts will be properties, and indeed there exists an independent motivation that we need these properties introduced by questions anyway. The reason is that we can explicitly refer back to such properties associated with questions by means of pronouns. Suppose Q asks *Who went to the party?*, then A can answer by *John believes that Mary was one of <u>them</u>*. The second sentence intuitively means that *John believes that Mary was one of those who went to the party*. This doesn't mean, of coarse, that John believes that Mary is one of those who *actually* went to the party. John's belief is not about whether Mary is an element of a certain rigid set of individuals or not, but about whether Mary has the property of being one who went to the party. That is, the description *those who went to the party* must have a *de dicto*, and no *de re* interpretation. This in turn suggests that what we need for the analysis of the question-answer relation is closely related with what we need for the analysis of descriptive pronouns.[2]

In the approach of Jäger (1996) the domain of quantification is restricted in a rather unconventional (but interesting) way. In the following, I want to propose a more conventional analysis of domain restriction, by assuming that questions introduce properties or relations into the discourse that are anaphorically taken up by the 'quantifier' *only* and figure as its domain of quantification. For instance, the domain of quantification for the occurrence of *only* in (b) should be, for each possibility of the context, the set of gentleman-table lady pairs such that John introduced the first to the second in the world of that possibility.

The domain of quantification of *only* should thus be restricted by a relation. The intended relation is the extension of the abstract associated with the question that the sentence in which *only* occurs answers. An abstract denotes a relation in intension. A relation in intension is of course a function from worlds to an extensional relation between individuals. Suppose that f denotes such a relation in intension. Then we can easily determine the partition induced by this relation on a set of worlds C: $\{\{w' \in C | f(w') = f(w)\} | w \in C\}$. My proposal is that questions not only partition the context, but also make the abstract that underlies this partitions anaphorically accessible.

According to the proponents of the propositional approach towards questions, the intension of a question is its set of its possible complete answers. Groenendijk & Stokhof (1984) have forcefully argued that at least for most questions their complete answers should be thought of as the cells of the partition induced by the abstracts associated with the sentences by which the question is asked. According to this approach, possible true answers to a question mutually exclude each other and should receive an *exhaustive* interpretation.

The focus sensitive operator *only* is an explicit *exhaustivity* marker and thus naturally used in answers to wh-questions. I will take over the suggestion of Groenendijk & Stokhof (1984), however, that also sentences containing bare *focal* constituents which are assertively used as answers to mention-all questions should be interpreted exhaustively. I will account for exhaustivity in terms of the meaning of *only*. In particular, I will assume that the logical representation of both (b) and (c), (c) *John introduced Bill to Mary*, will be "Only^{P}($\hat{x}$,$\hat{y}$Introduce(j,x,y), Bill, Mary)", if (c) is given as answer to a mention-all question like (a), where $\hat{x}$,$\hat{y}$Introduce(j,x,y) will denote a function from an information state and a tuple of individuals to an information state, and where p is a contextually given anaphoric pronoun that will denote a relation in intension between individuals.

Suppose we are in a situation where we know that some of the boys were teasing the girls non-collectively, then the question *Who was teasing whom?* can be appropriately answered by a discourse like *John teased Mary. Bill teased Sue and Dazy. And Harry teased all three of them* meaning that John only teased Mary, Bill only Sue and Dazy, and Harry all three of them. As observed by Büring (1995), the noun phrases *John, Bill* and *Harry* used in these answers typically have rising accents, while the noun phrases *Mary, Sue and Dazy*, and *all three of them* will get a falling accent. The falling, focal, accent indicates exhaustivity, and Büring hypothesises that rising, *topical*, accent indicates the existence of a further open question. This cannot be quite right, however, because although *Harry* will get topical accent, after the third sentence the relevant question is exhaustively answered. The hypothesis of Hendriks & Dekker (1996) seems more appropriate. They propose that topical accent indicates the use of a non-monotone anaphor. In our framework this can be accounted for by saying that the answer with topical accent doesn't give an exhaustive listing of the relation introduced by the question and anaphorically picked up by the answers.

Focal stress normally indicates exhaustivity. It seems, however, that not all uses of focus does so. It is at least not obvious how to interpret the answer *I can say the alphabet* given by a six year old boy to the question *Who can say the alphabet?* asked by the schoolteacher in an exhaustive way such that the boy doesn't want to imply that he is the only one who can do so. Indeed, I will assume that the above question is a *mention-some* question, and that although the use of focus-accent is appropriate in answers to mention-some questions, the focused constituent won't give rise to an exhaustive interpretation. Still, following Groenendijk (ms.), I will make use of the extra structure, or fine-grainedness, of the possibilities of the information states used in dynamic theories of discourse such that also

---

[2] See also Van Rooy (1997a, 1997b), and Zeevat (1994).

mention-some readings of questions partition the context, and that also all alternative complete answers to mention-some questions are represented by cells of a partition.[3] In distinction to the proposal of Groenendijk (ms.), however, I will do this in such a way that mention-some questions introduce individuals to each possibility of the context, without allowing singular pronouns to refer back to these individuals. Formally I will implement this by assuming that possibilities are triples that contain *two* assignment functions, such that all three elements of these triples help to determine the partition, but that only one of the two assignment functions is used for the interpretation of variables.

Formalisation[4]

The *syntax* for the language L will not be specified explicitly, but is given implicitly in the semantic clauses. *Models* are triples $\langle D, W, I \rangle$, where D is a non-empty set of *objects*, W a non-empty set of *possible worlds*, and I the intensional interpretation function that maps each *n*-ary relation to a function from worlds to a subset of the *n*-th Cartesian product of D. The set of *assignments*, G, is a set of functions that map individual variables to elements of D, and relation variables to functions from worlds to relations on D. *Possibilities* are triples, elements of $G \times G \times W$.[5] *Information states* are sets of sets of possibilities. I will demand that each information state S is partitioned, in the sense that no element of $\cup S$ is an element of more than one element of S. I will use the following notational conventions with assignments g, g' and h, objects $o_1,...,o_n$, variables $x_1,...,x_n$ and y, subset c of $G \times G \times W$, and worlds w, where $x_1,...,x_n \notin dom(g)$ and for no $\langle g,h,w \rangle \in c$: $x_1,...,x_n \in dom(g)$:

$$g[x_1..,x_n]h \text{ iff } dom(h) = dom(g) \cup \{x_1..,x_n\} \; \& \; \forall y \in dom(h)[y \notin \{x_1..,x_n\} \rightarrow h(y) = g(y)]$$
$$g[^{x_1}/_{o_1},...,^{x_n}/_{o_n}] = \{\langle y, g(y) \rangle | \, y \in dom(g) - \{x_1,...,x_n\}\} \cup \{\langle x_1,o_1 \rangle,...,\langle x_n,o_n \rangle\}$$
$$c[^{x_1}/_{o_1},...,^{x_n}/_{o_n}] = \{\langle g',h,w \rangle | \, \exists g{:}\langle g,h,w \rangle \in c \; \& \; g' = g[^{x_1}/_{o_1},...,^{x_n}/_{o_n}]\}$$

Possibilities are ordered by $\leq$: $\langle g,h,w \rangle \leq \langle g',h',w' \rangle$ iff $w = w'$ and $g \subseteq g'$. This ordering relation carries over to sets of possibilities c and c': $c \leq c'$ iff for every $\alpha \in c$: there is an $\alpha' \in c'$: $\alpha \leq \alpha'$. For information states S and S' to stand in the order relation $\leq$, $S \leq S'$, I not only demand that $\cup S \leq \cup S'$, but also that for each cell c in S there is a cell c' in S' such that $c \leq c'$.

The (static) 'term'-evaluation used below is defined by:

$$\|t\|^{g,h,w} \; = \; I_w(t), \text{ if t is an individual constant}$$
$$= \; g(t), \text{ if } t \in dom(g), \text{ and t is an individual variable, else}$$
$$= \; h(t)(w), \text{ if } t \in dom(h), \text{ and t is a relation variable,}$$
$$= \; \text{undefined otherwise}$$

Note that according to this rule, the assignment function h is irrelevant for the interpretation of individual terms. It will only be relevant for the interpretation of relation-variables and for determining fine-grained partitions in case of mention-some questions.

---

[3] Groenendijk (ms.) thereby closes the gap between the partition semantics of Groenendijk & Stokhof (1984) and the analyses of questions of Hamblin (1973) and Karttunen (1977) that were from the very beginning most suitable to analyse mention-some readings. Interestingly enough, Heim (1994) tries to close the gap between the different analyses of questions from the other side, and argues that to do so we need to make use of structured propositions. It is well known that there is a close correspondence between structured propositions and the information states used in recent theories of discourse.

[4] In the formalisation I take over some ideas from Groenendijk (ms) and Van Rooy (1997a).

[5] Assuming that E is a function that assigns to every world its set of existing individuals, I will assume that for every n there exists a distinguished variable ϕ such that for every possibility $\langle g,h,w \rangle$: $\|\phi\|^{g,h,w} = E(w)^n$.

Assuming that x and x_1 until x_n are individual variables, p, q and q_1 until q_n relation variables, and that w(<g,h,w>) = w, I can give the following recursive definition of the context change potential [[A]] $[\subseteq \wp(\wp(G \times G \times W)) \times \wp(\wp(G \times G \times W))]$ of formulae A of L:[6]

$$[[Rt_1...t_n]](S) \quad = \quad \{\{\alpha \in c | <||t_1||^{\alpha},...,||t_n||^{\alpha}> \in I_{w(\alpha)}(R)\} | c \in S\}$$

$$[[\hat{x}_1...\hat{x}_n A \upharpoonright p]](S) \quad = \quad \lambda<d_1,...,d_n>.[[A]](\{\{<g[^{x_1}/_{d_1},...,^{x_n}/_{d_n}],h,w> | <g,h,w> \in c \ \& <d_1,...,d_n> \in ||p||^{g,h,w}\} | c \in S\})$$

$$[[\hat{x}_1..\hat{x}_n A \upharpoonright p(t_1,..,t_n)]](S) = \{\{\beta | \exists\alpha \in c: \alpha \leq \beta \ \& \ \beta \in [[\hat{x}_1...\hat{x}_n A \upharpoonright p]](\{\{\alpha\}\})(<||t_1||^{\alpha},...,||t_n||^{\alpha}>)\} | c \in S\}$$

$$[[\sim A]](S) \quad = \quad \{\{\alpha \in c | \sim\exists\beta \in \cup([[A]](S)): \alpha \leq \beta\} | c \in S\}$$

$$[[A \wedge B]](S) \quad = \quad [[B]]([[A]](S))$$

$$[[\exists x A]](S) \quad = \quad \{\{\cup([[A]](\{c[^x/_d]\}))\} | d \in D \ \& \ c \in S\}^7$$

$$[[Q^q_{x,p}(A,B)]](S) \quad = \quad \{\{<g,h[^p/\hat{x},_q|A \wedge B\,^g_h],w> | <g,h,w> \in c \ \& \ [Q](\{d \in D | [[\hat{x}A \upharpoonright q]](\{\{<g,h,w>\}\})(d) \neq \{\emptyset\}\}, \{d \in D | [[\hat{x}(A \wedge B) \upharpoonright q]](\{\{<g,h,w>\}\})(d) \neq \{\emptyset\}\})\} | c \in S\}^8$$

$$[[\partial A]](S) \quad = \quad [[A]](S), \text{ if } S \leq [[A]](S),$$
$$= \quad \emptyset \text{ otherwise}^9$$

$$[[A?^{\exists x_1...x_n}]](S) \quad = \quad \{\{<g,h[^{x_1}/_{d_1},...,^{x_n}/_{d_n}],w> | <g,h,w> \in c \ \& \ \exists g',h': g' \supseteq g \ \& \ h' \supseteq h \ \& \ <g',h',w> \in \cup([[A]](\{c[^{x_1}/_{d_1},...,^{x_n}/_{d_n}]\}))\} | c \in S \ \& <d_1,...,d_n> \in D^n\}^{10}$$

$$[[A?_p{}^{x_1,q_1...x_n,q_n}]](S) \quad = \quad \{\{<g,h[^p/\hat{x}_1,_{q_1},...\hat{x}_n,_{q_n}|A\,^g_h],w'> | <g,h,w'> \in c \ \& \ \hat{x}_1,_{q_1},...\hat{x}_n,_{q_n}|A\,^g_h(w') = \hat{x}_1,_{q_1},...\hat{x}_n,_{q_n}|A\,^g_h(w))\} | c \in S \ \& <g,h,w> \in c\}^{11}$$

where the abstract $\hat{x}_1,_{q_1},...\hat{x}_n,_{q_n}|A\,^g_h$ is that function f: $W \rightarrow \wp(D^n)$ s.t. for any $w \in W$:

$$f(w) \quad = \quad \{<d_1,...,d_n> \in ||q_1||^{g,h,w} \times ... \times ||q_n||^{g,h,w} | [[A]](\{\{<g[^{x_1}/_{d_1},...,^{x_n}/_{d_n}],h,w>\}\}) \neq \{\emptyset\}\}$$

---

6 I neglect definedness conditions, and will say that A *entails* B, A⊨B, iff ∀S: $[[A]](S) \leq [[B]]([[A]](S))$.

7 Note that according to this interpretation rule of 'existential' sentences, for any cell of a partition it holds that all elements of this cell have the same assignment functions.

8 Where [Q] is the normal interpretation of the determiner Q. That quantifiers should introduce properties instead of sets is needed to account for the *de dicto* reading of *Most friends of Sue will marry a Swede. Mary believes they will be happy*.

9 The symbol ∂ should be thought of as a presupposition marker.

10 Thus, mention-some questions come with an existential 'presupposition', partition the context in the same way as a formula like "∃xA" does, but still don't introduce variables that refer to specific individuals to which we can refer back with singular pronouns. For example, if S = {{<g,h,w>,<g,h,w'>}, {<k,l,w">}}, D = {d,d'}, $I_w(P) = D$, $I_{w'}(P) = \{d\}$ and $I_{w''}(P) = \{d'\}$, then $[[Px?^{\exists x}]](S) = \{\{<g,h[^x/_d],w>, <g,h[^x/_d],w'>\}, \{<g,h[^x/_{d'}],w>\}, \{<k,l[^x/_{d'}],w''>\}\}$.

11 One reason to give a partition-semantics for questions is that in this way we can analyse *embedded questions* like *John knows who is sick* in a compositional fashion such that we need only one interpretation rule for *know*. We just represent such a sentence as "Know(j, Sick(x)?$_p{}^x$)", and interpret knowledge attributions as follows:
$[[Know(j, A)]](S) = \{\{<g,h,w> \in c | \{\{<g,h,w''> | w'' \in K(j,w)\}\} \leq [[A]](\{\{<g,h,w''> | w'' \in K(j,w)\}\})\} | c \in S\}$
By the assumption that the accessibility function, K, for knowledge is reflexive, we can account for embedded questions in a compositional way such that we can infer *John knows that Mary is (not) sick* from *John knows who is sick* and *Mary is (not) sick*, just like Groenendijk & Stokhof (1984), but in a slightly different way.

If we represent a mention-all question like *Who is sick?* by "Sick(x)?$_p$^{x}q", we introduce the variable *p* to the discourse that denotes in every world the set of all persons in the set denoted by *q* that are sick in that world, thus, the variable gets an exhaustive interpretation restricted to the set denoted by *q*. The introduced variable *p* then helps to determine what proposition is expressed by an answer to this question, and for pronouns that can pick up the property introduced by this question.

To determine what is expressed by an answer in which the word *only* occurs, I will limit myself for simplicity to cases where the focused constituents denote individuals, and where their 'alternative sets' also contain only individuals.[12] In that case we might use the interpretation rule of *only* proposed by Von Stechow (1989) but now implemented in our dynamic theory:

$$[[\mathrm{OnlyP}(R,t_1,....,t_n)]](S) = \{\{\alpha \in c | [[R \restriction p]](\{\{\alpha\}\})(<[[t_1]]^\alpha,\ldots,[[t_n]]^\alpha>) \neq \{\varnothing\} \ \& \ \forall <d_1,...,d_n> \in D^n: [[R \restriction p]](\{\{\alpha\}\})(<d_1,...,d_n>) \neq \{\varnothing\} \Rightarrow <d_1,...,d_n> = <[[t_1]]^\alpha,\ldots,[[t_n]]^\alpha>\} | \ c \in S\}$$ [13]

I will assume that sentences in which a focused constituent occur without an explicit exhaustive operator, like "*John* came to the party", are either answers to mention-all questions, and should be represented by a formula like "OnlyP(R, j)", or they are answers to mention-some questions, and should be represented by something like "$\partial(\exists x \hat{y} Ry \restriction p(x)) \wedge j = x$". As an answer to a mention-all question, it presupposes the existence of a property that underlies a partition induced by a mention-all question, and as an answer to a mention-some question, it presupposes the partition induced by a mention-some question with its correspondent existential presupposition.

Literature

Büring, D. (1995), 'Topic', In: P. Bosch & R. v.d. Sandt (eds.), *The Focus Book*, IBM, Heidelberg.

Hamblin, C. (1973), 'Questions in Montague English', *Foundations of Language*, 41-53.

Groenendijk, J. and M. Stokhof (1984), *Studies in the Semantics of Questions and the Pragmatics of Answers*, Ph.D. thesis, University of Amsterdam.

Groenendijk, J. (ms), 'Questions in Dynamic Semantics', handout of talk given in Munich, March 1997.

Heim, I. (1994), 'Interrogative semantics and Karttunen's semantics for Know', In: R. Buchalla and A. Mittwoch (eds.), *IATL 1*, Akademon, Jerusalem.

Hendriks, H. and P. Dekker (1996), 'Links without locations', In: P. Dekker & M. Stokhof (eds.), *Proceedings of the 10th Amsterdam Colloquium*, Amsterdam, 339-358.

Jäger, G. (1996), 'Only updates', In: P. Dekker & M. Stokhof (eds.), *Proceedings of the 10th Amsterdam Colloquium*, Amsterdam, 387-405.

Karttunen, L (1977),'Syntax and semantics of questions', *Linguistics and Philosophy*,1, 3-44

Rooth, M. (1985), *Association with Focus*, Ph.D. thesis, University of Massachusets, Amherst.

Rooth, M. (1992), 'A theory of focus interpretation', *Natural Language Semantics*, 1, 75-116.

Rooy, R. van (1997a), *Attitudes and Changing Contexts*, Ph.D. dissertation, Stuttgart.

Rooy, R. van (1997b), 'Descriptive pronouns in dynamic semantics', these proceedings.

Stechow, A. von (1989), 'Focusing and backgrounding operators', Technical Report 6, Fachgruppe Sprachwissenschaft, Universität Konstanz.

Zeevat, H. (1994), 'Questions and exhaustivity in update semantics', In: Bunt *et al.* (eds.), *International Workshop on Computational Semantics*, Tilburg, 211-219.

Zimmermann, T. E., (1985), 'Remarks on Groenendijk and Stokhof's theory of indirect questions', *Linguistics and Philosophy*, 8, 431-448.

---

[12] For cases where the 'alternatives' are quantifiers, a more complicated analysis of *only* is needed. See Groenendijk & Stokhof (1984) and Von Stechow (1989) for their more general treatment of exhaustivity.

[13] Where R is an n-ary relation of the form $\hat{x}_1 \ldots \hat{x}_n A$.

Topic, Focus, and Quantifier Raising

Kjell Johan Sæbø
University of Oslo

This paper investigates the correlation between information structure and quantifier scope. It has often been noted that intonation seems to influence scope relations, yet noone has given a satisfactory account of this influence. I try to show that Quantifier Raising in a language like English depends on information structure, and thus indirectly on intonation, in much the same way as does DP scrambling in a language like German. I propose a theory where Quantifier Raising emerges as a side effect of a more general operation, covert in a language like English but overt in a language like German.

1 Introduction

It has been widely assumed that sentences like (1) or (2) are ambiguous between the reading where the subject or adverb has scope over the object and an **inverse** reading, where the object takes scope over the subject or adverb.

(1) A woman loves every man. (Montague 1970)
(2) He doesn't hate most of the songs. (Jackendoff 1972)

Various techniques have been devised for deriving this category of inverse readings. Generative grammarians have tended to assume in some form the LF movement operation **Quantifier Raising**. The object would get wide scope by raising covertly to some position ultimately c-commanding the subject (or a trace of it) or adjunct.

Now, as Chomsky (1995: 377) puts it, the status of Quantifier Raising (QR) has been the topic of much controversy. One issue is the issue of **overgeneration**. Unless the operation is constrained, it creates readings not intuitively available. There are two aspects of this: The **crosslinguistic** and the **prosodic** aspect.

There are languages where QR evidently has no role to play. One is German, where (Frey 1993) scope ambiguities can only come about through overt movement of a QP, topicalization or scrambling. It is of course desirable to derive such facts from other properties of the language. It can be shown, however, that syntactically based attempts at constraining (Aoun and Li 1993) or eliminating (Kitahara 1992) LF Quantifier Raising cannot carry over to German.

The prosodic issue can be formulated thus: Why is it that, as many have noted, inverse readings may be more or less available, depending on intonation? A sentence may be ambiguous on paper, but once it is spoken, the ambiguity may be resolved. Intonation is taken to convey partial information about discourse or information structure, and some (Kadmon and Roberts 1986, Büring 1996) have tried to draw a connection between scope and notions like topic and focus. Others (Krifka 1994) have attempted to build a bridge between scope and accentuation via syntax.

These approaches offer valuable insights, but none gives a complete answer to the question of the relation between prosody and scope. I suggest that scope inversions attributed to QR depend on information structure in a similar way as the partition of a sentence into the restrictor and the nuclear scope of a quantificational adverb. In particular, I hypothesize that an object QP can undergo QR iff it is (S-) topical. In a general sense, this idea is in tune with a position held by Praguian linguists (cf. e.g. Peregrin 1996: 241), and with aspects of the work of Diesing (1992).

The idea that QR depends on topicality is interesting in relation to German, where there is no (covert) QR but there is (overt) DP scrambling, an operation commonly assumed to (i) extend the scope of a QP and (ii) be information structurally motivated. This opens the prospect of dispensing with QR as a separate notion. It is imaginable that QR is just a special case – the truth-conditionally visible subset – of a more general DP raising operation, covert in English but overt in German.

I follow von Fintel (1994), Büring (1996), and Vallduví and Engdahl (1996) in assuming, in principle, a three-way partition of a sentence into (1) a topic (also termed sentence-, or S-topic, or theme), (2) a ground (also termed discourse-, or D-topic), and (3) a focus (also termed rheme), where a topic may be absent. The topic and the focus consist in new information and will contain an accent.

It can be difficult, notably in English, to distinguish between topic and focus; i.e. to tell in a sentence with two accents which marks the topic and which the focus. Both in this regard and concerning the range of the topic or focus marking, i.e. how far it projects, grammatical signals underdetermine the information structure. It has been claimed that certain tones, like the English fall–rise, identify a topic, but in general, only the larger discourse ultimately disambiguates the structure.

It is customary to let a question play the role of a disambiguating context. In an answer to a wh question, what corresponds to the wh word will count as focus. There may now be another piece of information not given in the question, a topic, as in indirect answers like (3) and (4). In the terms of Büring (1996), in (3) we have a case of a **partial** topic, while in (4) we have a case of a **contrastive** topic. Characteristically, a phrase containing a new information topic modifies a given phrase, specifying it, as in (3), or substituting an alternative, as in (4).

(3) – Who harvested the vegetables?
– I think the CHILDREN harvested the CARROTS.
FOCUS TOPIC

(4) – Who is going to pick the apples?
– I heard that the PARENTS are to pick the PEACHES.
FOCUS TOPIC

2 QR and German

Beck (1996: 44) conjectures that because in German, scope order *can* be made clear at S-Structure, it has to be. One interpretation of this idea is that whatever features drive QR are 'strong' in German, causing overt movement. This overt movement – predominantly scrambling – affects not only QPs but DPs in general, and, what is commonly assumed to induce it – primarily information structural factors – seems to work in a uniform way for QPs or other DPs. This makes it sensible not to consider "overt QR" separately but to view it as a case of a more general operation.

2.1 Scrambling and Information Structure

According to Rosengren (1993: 290ff.), scrambling is a means for a constituent to escape the 'nuclear focus domain' and maybe to form a separate focus domain, whereas Haftka (1994: 148ff.) considers scrambling as movement to the specifier of a topic (or secondary focus) category, to have the corresponding feature checked. In particular, there is a tendency for a topic to scramble across a focus, as shown in (5) and (6), direct translations of (3) and (4) above, respectively.

(5) – Wer hat das Gemüse geerntet?
– Ich glaube, daß [die MOHRRÜBEN]$_T$ [die KINDER]$_F$ ernteten.

(6) – Wer wird die Äpfel pflücken?
– Ich habe gehört, daß [die PFIRSICHE]$_T$ [die ELTERN]$_F$ pflücken sollen.

According to informants, the base order versions are less felicitous. This agrees with the stipulation made by Büring (1996: 57) that "there is a constraint banning the surface order Focus before S–Topic". Specifically, a focus cannot scramble across a topic. Generally, it seems that what makes an object scramble or topicalize across a subject or an adjunct is primarily its function as a topic in the sentence.

2.2 Scrambling and Quantification

We know that in German, an object QP can only outscope a VP adjunct or a subject QP if it overtly moves across it. The last section concluded that such overt movement is highly sensitive to the information structural status of the object DP. Essentially, it should include a topic. What this amounts to is that an object QP can only outscope a VP adjunct or a subject QP if it includes a topic. In (7), the object includes a focus and we do not get scrambling, while in (8), the object includes a topic and we do get scrambling:

(7) – Wieviele der Romane haben die Schüler gelesen?
how many the novels have the students read
a. – Da hat [fast JEDER]$_T$ Schüler [mindestens EINEN]$_F$ Roman gelesen.
there has almost every student at least one novel read
b. ?? – Da hat [mindestens EINEN]$_F$ Roman [fast JEDER]$_T$ Schüler gelesen.

(8) – Wieviele der Schüler haben die Romane gelesen?
how many the students have the novels read
a. – Da hat [mindestens EINEN]$_T$ Roman [fast JEDER]$_F$ Schüler gelesen.
there has at least one novel almost every student read
b. ? – Da hat [fast JEDER]$_F$ Schüler [mindestens EINEN]$_T$ Roman gelesen.

(7)a. only has the reading where the subject scopes over the object, while (8)a. in addition has the reading where the object scopes over the subject. Summing up:

- An object QP cannot scope over a VP adjunct or a subject QP if it is focal and the adjunct or subject is topical, but it can if it is the other way around.

This result is not only valid as long as the relevant constituents are confined to the middle field but also as soon as the forefield is taken into account. Thus (9)a. is unambiguous while (9)b. is ambiguous. The former fact argues against the analysis of Krifka (1994), which does not distinguish between a topic and a focus accent.

(9) a. – Wieviele der Romane haben die Schüler gelesen?
– [Fast JEDER]$_T$ Schüler hat [mindestens EINEN]$_F$ Roman gelesen, ...
almost every student has at least one novel read
b. – Wieviele der Schüler haben die Romane gelesen?
– [Fast JEDER]$_F$ Schüler hat [mindestens EINEN]$_T$ Roman gelesen, ...

3 QR and English

I aim to show in this section that information structural factors influence QR in English. The idea is not new, as it has repeatedly been noted that intonation seems to play a role in this regard. As I see it, intonation is an indicator of information structure, but not a perfect one. Specifically, I aim to show that in a sufficiently clear context, what counts as focus cannot undergo QR across something which counts as topic, while the converse is throughout possible and often even preferred.

3.1 QR: Topic and Focus

Consider the following hypothesis.

- A focal object QP cannot scope over a topical subject QP or VP adjunct. But a topical object QP can scope over a focal subject QP or VP adjunct.

We need to clarify what we mean by a focal or topical QP. Let us say that a focal or topical QP is a QP which includes, properly or improperly, a focus or topic, or is included in a focus or topic. Let us start by considering indirect, more precisely, **partial answers to wh questions where a determiner is a (partial) topic.**

(10) a. – How many meetings did the candidates attend?
– [SEVERAL]$_T$ candidates attended [EVERY]$_F$ meeting.
b. – What did the candidates attend?
– [SEVERAL]$_T$ candidates attended [every MEETING]$_F$.
c. – What did the candidates do?
– [SEVERAL]$_T$ candidates [attended every MEETING]$_F$.

(10) testifies to the first half of the hypothesis: Whether the focus is wide or narrow, the declarative sentence doesn't have a reading where the focal object QP scopes over the topical subject QP. For the second half of the hypothesis, consider (11).

(11) a. – How many candidates attended the meetings?
– [SEVERAL]$_F$ candidates attended [EVERY]$_T$ meeting.
b. – Who attended the meetings?
– [Several CANDIDATES]$_F$ attended [EVERY]$_T$ meeting.
c. – What happened at the meetings?
– [Several CANDIDATES ATTENDED]$_F$ [EVERY]$_T$ meeting.

Here, the declarative sentence does have a reading on which the object QP, now topical, scopes over the now focal subject QP. We may vary the determiners and thereby increase or decrease the plausibility of one or the other interpretation. In principle, however, there will be two readings in these cases. Another way to vary the examples is to widen the topic, as in (12), where in a. the (implicitly partitive) subject QP and in b. the (implicitly partitive) object QP is the topic. Again, the focal object cannot scope over the topical subject, while the converse is possible.

(12) a. – How many meetings did the candidates attend?
– [Several DEMOCRATS]$_T$ attended [EVERY]$_F$ meeting.
b. – How many candidates attended the meetings?
– [SEVERAL]$_F$ candidates attended [every RALLY]$_T$.

The above hypothesis is also concerned with the scope interaction between a VP adjunct and an object QP. Indeed, we observe that as a partial answer to a wh question, a sentence with a quantificational adjunct and a quantificational object can have different readings according to whether the adjunct is a (partial) topic and the object includes a focus, as in (13)a., where QR is evidently not possible, or whether it is the other way around, as in (13)b., where QR is evidently possible.

(13) a. – How many of these pieces do you play when you give a concert?
– We [USUALLY]$_T$ play [two or THREE]$_F$ of them.
b. – How often do you play these pieces when you give a concert?
– We [USUALLY]$_F$ play [two or THREE]$_T$ of them.

The ambiguity of b. is a problem for the analysis of Kadmon and Roberts (1986), who treat a parallel case as unambiguous, considering only a context parallel to a.

3.2 Other Cases

We have only been considering answers to questions, as these contexts are particularly good indicators of the topic–focus structure. Other contexts may be less clear. But it is possible to find declarative environments identifying one QP as focal and another as topical. Citing (14)a., Lakoff (1971) remarks that the inverse reading is easier to get with heavy stress on the determiner. (14)c. seems to be the sort of setting where the accent has this effect, while in (14)b. this reading is blocked:

(14) a. Many men read few books.
b. The recent survey of the reading habits of American males revealed that [many]$_T$ men read [few books]$_F$.
c. The recent statistics from the publishers' association shows that [many]$_F$ people read [few]$_T$ books.

We may also consider what might be natural contexts for (slight modifications of) (15)a.: (15)b., where the object is focal and the inverse reading is not available, and (15)c., where the object is topical and the inverse reading is available.

(15) a. Somebody loves everybody.
b. The staff in the orphanage are very caring people.
Some love every child.
c. The children in the orphanage are happy.
Somebody on the staff loves everybody.

Furthermore, we have only been concerned with the relative scope of two phrases where one is topical and the other is focal. It is desirable to strengthen the above hypotheses to say that an object can scope over a subject or adjunct iff it is topical. However, it does seem possible for a focus to scope over a ground. What can be said about the relevant cases is that they do not necessarily involve movement. Then we can maintain the following generalization: An object can take scope over a subject or an adjunct *by movement* if and only if it is topical.

A note on *can*: It is predicted that a sentence with a topical object is ambiguous. This can be modelled in two ways. Either we say that QR is optional. (Note that in German, scrambling is hardly ever mandatory.) Or, we say that QR can be reconstructed, only that reconstruction is not conceived of as backward movement. Rather, there is the possibility that the raising operation leaves a trace of type ⟨⟨e,t⟩,t⟩, in which case it does not have a scopal effect (Heim and Kratzer 1997).

4 Conclusions

I have tried to show that in English, such scope inversions that are assumed to come about through QR are subject to information structural constraints. This result is interesting in itself, as it answers the question of why such scope inversions seem to depend on intonation. However, it is even more interesting to compare English with German in this regard and to note that these constraints are more or less the same as those underlying the overt raising operation known as DP scrambling, and that beyond scrambling, there is no German counterpart to Quantifier Raising.

If we choose a strong interpretation of these facts, we are able to answer two more questions: Why should QR be constrained by information structure? And: Why is QR covert in English but overt in German? We may say that QR is constrained by information structure because QR is information structurally driven. And, QR is covert in English but overt in German because scrambling is overt in German but covert in English. This, in turn, might be phrased as a weak–strong distinction in the relevant information structural feature, a *topic feature*.

The assumption of a general covert 'topic' operation in English may be dubious, notably from the point of view of economy. In fact, Fox (1995) has argued that QR takes place only if it creates another reading. This may cause us to choose a weaker interpretation. Anyway, if the representation of the facts is correct, we should be able to dispense with the notion of QR as a separate and ill understood phenomenon. Quantifiers do not raise because they are quantifiers but because they are topics. Thus QR reduces to operations which may remain ill understood syntactically but for which we have to provide an explanation independently – such as scrambling. So if further research can confirm the picture, a significant set of ambiguities – scope ambiguities supposed to involve QR – emerge as ultimately pragmatic ambiguities, partially resolved by the information structure of the sentence.

References

Aoun, Joseph and Yen-hui Li (1993) *Syntax of Scope.* Cambridge, Mass.

Beck, Sigrid (1996) "Quantified Structures as Barriers for LF Movement", in Natural Language Semantics 4, 1–56.

Büring, Daniel (1996) *The 59th Street Bridge Accent.* University of Tübingen dissertation (SfS Report 05–96).

Chomsky, Noam (1995) *The Minimalist Program.* Cambridge: MIT Press.

Diesing, Molly (1992) *Indefinites.* Cambridge, Mass.: MIT Press.

Fox, Danny (1995) "Economy and Scope", in Natural Language Semantics 3, 283-341.

Frey, Werner (1993) *Syntaktische Bedingungen für die semantische Interpretation.* Berlin: Akademie Verlag.

Heim, Irene and Angelika Kratzer (1997) *Semantics in Generative Grammar.* Oxford: Blackwell.

Haftka, Brigitta (1994) "Wie positioniere ich meine Position? Überlegungen zu funktionalen Phrasen im deutschen Mittelfeld", in Haftka (ed.) *Was determiniert Wortstellungsvariation?*, Opladen: Westdeutscher Verlag, 139–159.

Kadmon, Nirit and Craige Roberts (1986) "Prosody and Scope: The Role of Discourse Structure", in *CLS 22 Part 2*, 16–28.

Kitahara, Hisatsugu (1992) "Checking Theory and Scope Interpretation without Quantifier Raising", in Harvard Working Papers in Linguistics 1, 51–71.

Krifka, Manfred (1994) "Focus and Operator Scope in German", to appear in Bosch and van der Sandt (eds.) *Focus and NLP*, Cambridge University Press.

Lakoff, George (1971) "On Generative Semantics", in Steinberg and Jakobovits (eds.) *Semantics*, Cambridge University Press, 232–296.

Peregrin, Jaroslav (1996) "Topic and Focus in a Formal Framework", in Partee and Sgall (eds.) *Discourse and Meaning*, Amsterdam: Benjamins, 235–254.

Rosengren, Inger (1993) "Wahlfreiheit mit Konsequenzen – Scrambling, Topikalisierung und FHG im Dienste der Informationsstrukturierung", in Reis (ed.) *Wortstellung und Informationsstruktur*, Tübingen: Niemeyer, 251–312.

Vallduví, Enric and Elisabet Engdahl (1996) "The linguistic realization of information packaging", in Doherty (ed.) *Information structure: a key concept for translation theory*, Linguistics 34, 459–519.

Quantification in Dynamic Semantics

Maria Aloni
ILLC/Department of Philosophy, University of Amsterdam

Abstract

In dynamic semantics three styles of quantification have been proposed that can be seen to involve two different ways of interpreting free and quantified variables:

- Variables as denoting single partial objects;
- Variables as ranging over a number of alternative total objects.

I will show that the first view leads to problems of underspecification and the second to problems of overspecification. I will propose a new style of dynamic quantification in which variables are interpreted in a way which avoids these problems:

- Variables as ranging over a number of alternative definite objects (concepts).

By relativizing quantification to ways of conceptualizing the domain, we avoid the cardinality problems which arise if quantification is over concepts rather than objects.

Background and Motivation

In dynamic semantics, sentences characterize transitions across a space of information states. Information states are generally defined as sets of possibilities (here world-assignment pairs) and meanings describe shifts from states to states: updating with sentences may lead to smaller states in which possibilities have been eliminated, or to richer ones in which new discourse items have been added. Atoms, for example, yield smaller states resulting from eliminating those world-assignment pairs that do not satisfy them. Existential sentences lead to richer states: $\exists x \phi$ adds x and selects a number of possible values for it; the fact that in the output state(s) x is defined means that recurrences of x in later sentences can refer anaphorically. Information about variables is generally modelled in one of the two following ways:
1. Variables are interpreted as single *partial* objects.[1] The introduction of new items is defined in terms of *global extensions* that involve adding fresh variables and assigning them as possible values all elements of the universe.
2. Variables are taken to range over a number of *total* objects. The introduction of a new item is defined in terms of *individual extensions* that lead to the states resulting from adding a variable and assigning it as value a single element of the universe.[2]

1. Global Extension 2. Individual Extension

[0] Special thanks to: David Beaver, Paul Dekker, Jelle Gerbrandy, Jeroen Groenendijk and Andreas Liu.

[1] Partial objects are functions that assign to each possibility in a state the value of the corresponding variable in that possibility. A partial object is total if it is a constant function. For a formal definition cf. [2].

[2] In the pictures the universe consists only of two individuals a and b.

Global extensions yield unique output states, whereas individual extensions produce as many different outputs as there are members of the universe. This involves splitting up the initial state into different alternatives: later sentences will be processed with respect to each of them in a parallel fashion.

In the literature three different interpretations have been proposed for the dynamic existential quantifier that involve one or the other way of interpreting free[3] or quantified variables:

Random Assignment (RA) is the standard interpretation procedure for the dynamic existential quantifier. It is defined in terms of global extension. In this way quantified and free variables are interpreted uniformly as single indefinite partial objects, where further updates will tend to make these objects more definite and less partial. (Cf. [2,7,9,11].)

Slicing (SL) is defined in terms of individual extension: it involves splitting up the update procedure, so that the individuals that a variable can take as possible values are considered one by one, as disjunct alternatives, and not all at once. In this way, quantified and free variables are interpreted uniformly as ranging over a number of alternative total objects, where further updates will tend to eliminate certain alternatives. (Cf. [5].)

Moderate Slicing (MS) follows the slicing procedure as long as we are inside the syntactic scope of a quantifier, but lumps the remaining alternatives together once we are outside its scope. In this way, quantified variables range over a number of alternative total objects, whereas free variables are interpreted as single partial objects. (Cf. [1,3,8].)

These different styles of quantification lead to different results only when combined with non-distributive operators,[4] such as epistemic modals (cf. [2,5,8,12]) or presuppositions (cf. [1,10]). In this paper I will consider only epistemic modals. Modal sentences are interpreted in Veltman's style, as consistency tests. Updating with $\Diamond\phi$ involves checking whether ϕ is consistent with the information encoded in the input state σ. If the test succeeds, i.e. if at least one world-assignment pair in σ survives an update with ϕ, then the resulting state is σ itself; if the test fails, the output state is the empty set, the absurd state.

Although the analysis of combinations of quantifiers and non-distributive operators motivated the use of (moderate) slicing instead of random assignment, I will argue that precisely in such contexts critical problems emerge for all three approaches. The reason is that, of the two ways of interpreting variables that play a role in these approaches, the one that treats variables as single partial objects is too weak and leads to *problems of underspecification*, and the other that views them as a number of alternative total objects is too strong and leads to *problems of overspecification*. These problems occur for both quantified and free variables.

Underspecification and Overspecification

Problem 1: Treating variables in the syntactic scope of an existential quantifier as single partial objects has the unacceptable result that $\exists x\Diamond\phi \models \forall x\Diamond\phi$ (Dekker's problem, cf. [2]).[5] The sentences (1a) $\exists x\Diamond Px$(*Someone might be knocking at the door.*) and (1b) $\exists y\neg\Diamond Py$ (*Someone is certainly not knocking at the door.*) contradict each other if we assume RA. The variables x and y, being introduced via global extension, will denote exactly the same single underspecified object, which either

[3] By a 'free' variable, I mean a variable not occurring inside the syntactic scope of a quantifier. Typically, such 'free' occurrences may still be dynamically bound by a quantifier.

[4] Non-distributive operators are those that take the state holistically and not pointwise with respect to the possibilities in it. So it is not surprising that when we update with a non-distributive sentence, it matters which possibilities are lumped together to form a state and which are kept separate during the procedure.

[5] Heim's fat man problem (cf. [10]), predicting wrong presuppositions, has the same source.

verifies the modal sentence (if at least one member of the universe has the property P in some world) or falsifies it. In RA, quantified variables don't vary enough: the one value that a variable can take cannot be considered separately from the others because all the possible values are lumped together.

Problem 2: If we use slicing, problem 1 does not occur, but the total interpretation of free variables that SL involves leads to the loss of a number of attractive properties guaranteed by RA and MS, for instance the consistency[6] of sentences like (2) $\exists x Px \wedge \forall y \Diamond x = y$ (*Someone is knocking at the door. It might be anyone*). If all variables range over alternative total objects, these sentences become contradictory: it is impossible for one individual to be (possibly) identical to all the others (if $|D| > 1$).

Problem 3: The use of moderate slicing avoids the problems noted above, but runs into several others connected with the notions of support and coherence.[7] For example, consider the sequence (3) $\exists x \Diamond Px \wedge \neg Px$ (*Someone might be knocking at the door. She is not knocking at the door*). Intuitively (3) cannot be coherently asserted, but if we treat variables as denoting single partial objects, we can easily find a state that supports it, so (3) comes out not only consistent, but also coherent. Let σ be a state consisting of two possibilities that supports the information that either individual a or individual b is P, but it is not known which. It is easy to show that such a σ supports (3) given MS (or RA). The first conjunct is supported and leads to a state with four possibilities in which both a and b are assigned as possible values to x for each world. Updating with the second conjunct keeps only those two possibilities that assign to x the individuals that are not P. Note that even if the latter update eliminates possibilities, both possibilities in the initial state survive in the final state. So σ supports the sequence and hence the latter is coherent. Note that slicing, which involves a splitting in the interpretation procedure, avoids this problem: the two initial possibilities do not survive together in any of the output states. This kind of example shows that the notion of support in MS (and RA) is not compositional: we have a state that supports a conjunction, whereas the same state updated with the first conjunct does not support the second one.

Problem 4: As for problems with quantified variables, consider the following discourse uttered in a situation in which the identity of the culprit is unknown:[8] (4) *The culprit did it; so it is not the case that anyone might be innocent. But Alfred might be innocent, Bill might be innocent, ... So anyone might be innocent.* This example shows, among other interesting facts, that we do not always quantify over individuals, but sometimes (e.g., if epistemic modals are involved) over typically non-rigid concepts. So (moderate) slicing, and in general classical quantification, which lets variables range over total objects, is not fully adequate.

	RA	SL	MS
quantified variables	partial $\rightsquigarrow$ problem 1	total $\rightsquigarrow$ problem 4	total $\rightsquigarrow$ problem 4
free variables	partial $\rightsquigarrow$ problem 3	total $\rightsquigarrow$ problem 2	partial $\rightsquigarrow$ problem 3

Proposal

In order to overcome these problems of over- and underspecification, I propose a new style of dynamic quantification that lies between random assignment and slicing, and which treats free and quantified variables in a uniform way. As in slicing, the interpretation will proceed on different parallel levels so that free and quantified variables range over alternative definite members of some domain and do

[6]A sentence ϕ is consistent iff updating with ϕ does not always result in the empty set.

[7]A state σ supports a sentence ϕ iff each possibility in σ survives in the state resulting from updating σ with ϕ. A sentence is coherent iff there is a non-empty state that supports it. For formal definitions cf. [8].

[8]For more about this kind of example cf. [6].

not denote single indefinite objects; in this way variables will vary enough to avoid the underspecification problems 1 and 3. On the other hand the overspecification problems 2 and 4 are solved by allowing not one but many ways of identifying the objects we quantify over: different domains will arise from different ways of structuring conceptually the universe of discourse. Each conceptualization that covers the whole universe and does not consider any individual more than once will provide a suitable candidate for the domain of quantification. In this way quantifiers may range not only over the set of total objects but also over sets of non-rigid concepts.

Subjects in a State

A first step towards a solution consists in recognizing the difference between the partial objects that caused the underspecification problems, and the still partial but definite objects whose absence from the domain of quantification led to the overspecification problems. The notions defined in this section will provide a way of distinguishing them.

I assume two levels of objects: the individual elements of the universe of discourse that are given once and for all, and the inhabitants of the states. These inhabitants are structured, partial entities introduced as subjects in conversation; they can change, for instance by growing less partial, as the conversation proceeds. So I extend Dekker's definition of partial objects (cf. [2]) and call a *subject* in an information state any mapping from the possibilities (world-assignment pairs) in the state to the individuals in the universe of discourse. Note that besides explicitly introduced discourse items, potential items also count as subjects in a state.

Among the subjects, we can distinguish *rigid subjects* and *(in)definite subjects.* Rigid subjects are the constant functions among the subjects. Intuitively, they represent the elements of the universe of discourse at the level of the state. Definite subjects are those assigning the same value to all possibilities that share the same world. They are contextually restricted (individual) concepts. They are *definite* in that they have a single value relative to a single world, but *partial* in that they may have different values relative to different worlds. Indefinite subjects are subjects that are not definite, i.e. those assigning different values to possibilities with the same factual content.

In random assignment, variables denote possibly indefinite subjects (*partial*). In slicing, variables range over rigid subjects (*total*). I will let variables range over definite subjects (*definite*).

	x
w_1	a
w_1	b
w_2	a
w_2	b

1. partial

	x
w_1	a
w_2	a

	x
w_1	b
w_2	b

2. total

	x
w_1	a
w_2	a

	x
w_1	a
w_2	b

	x
w_1	b
w_2	a

	x
w_1	b
w_2	b

3. definite

However, as is evident from the picture above, the set of all definite subjects in a state cannot serve as the quantificational domain. The fact that there are strictly more concepts in a state than individuals in the universe of discourse would create problems, even in a language as poor as ours (without numerals and the like). For instance, a sentence like *Someone did it, but anyone might be innocent.* would come out inconsistent because if the first conjunct is supported, there will be an element in our quantificational domain that falsifies the universal sentence, namely the concept corresponding to the one who did it.

To avoid these problems, I introduce the notion of a conceptual cover that will provide a suitable way of restricting contextually the set of concepts.

Conceptualizations

Given a model consisting of a non-empty set W of worlds and a non-empty set D of individuals, I will call a *conceptualization* any set of functions from W to D. A conceptualization is a way of structuring the domain. In principle, any conceptualization may constitute a domain of quantification given the right context, but I propose two reasonable conditions that give rise to the desired cardinality results: *exhaustiveness* and *disjointness*. A conceptualization is exhaustive if every individual in D is considered at least once in each world, and it is disjoint if no individual is considered more than once in each world, i.e. if its elements do not overlap. I will call any conceptualization that satisfies both conditions a *conceptual cover*.

Definition 1 [Conceptual Cover] Let $\mathcal{M} = \langle W, D \rangle$. The set $\mathcal{C}_{\mathcal{M}}$ of conceptual covers on $\mathcal{M}$ is defined as:
$\mathcal{C}_{\mathcal{M}} = \{CC \subseteq D^W \mid \forall w \in W : \forall d \in D : \text{ there is a unique } c \in CC : c(w) = d\}$.

By exhaustiveness and disjointness we get the desired cardinality results:
Fact 1. For any conceptual cover $CC \in \mathcal{C}_{\langle W,D \rangle}$, it holds that $|CC| = |D|$.

Among the conceptual covers we find the set of all rigid individual concepts:
Fact 2. $RC = \{c \in D^W \mid \forall w, w' \in W : c(w) = c(w')\}$ is in $\mathcal{C}_{\langle W,D \rangle}$.
Note, however, that RC is just one among many possible CC.[9]

My proposal is to let variables range over the elements of a contextually-supplied conceptual cover. To do this I need to define an operation that extends information states in the appropriate way.

Definition 2 [Information States] Let $\mathcal{M} = \langle D, W \rangle$ be a model for a language $\mathcal{L}$. Let $\mathcal{V}$ be the set of individual variables in $\mathcal{L}$. The set $\Sigma_{\mathcal{M}}$ of information states based on $\mathcal{M}$ is defined as $\Sigma_{\mathcal{M}} = \bigcup_{X \subseteq \mathcal{V}} \mathcal{P}(W \times D^X)$.

A state is a set of world-assignment pairs in which the assignments share the same domain. C-extensions are operations over states.[10]

Definition 3 [c-extensions] For $c \in D^W$: $\sigma[x/c] = \{i[x/d] \mid c(w_i) = d \ \& \ i \in \sigma\}$.

C-extensions lie between global and individual extensions: they introduce fresh variables and interpret them as certain definite subjects. Dynamic quantifiers are defined in terms of c-extensions; they range over elements of a contextually-given conceptual cover and not (or only indirectly) over the individuals in the universe. In this way, quantification is relativized to ways of conceptualizing the domain. The objects we quantify over (talk or think about) are not given atoms, but are structured, possibly partial entities arising from our ways of organizing conceptually our own experience. Dynamic quantification is defined as follows:[11]

Definition 4 [Quantification] $\sigma[\exists_{CC} x]_a \sigma'$ iff $\sigma' = \sigma[x/c]$ for some $c \in a(CC)$.

CC is a free variable ranging over conceptual covers whose value is supplied by a, which represents the pragmatic context. The fact that each quantifier occurs with its own index allows different quantifiers to range over different domains. Shifts of

[9] Note that given $M = \langle D, W \rangle$ there are $(|D|!)^{|W|-1}$ conceptual covers on M.
[10] The operation $[x/d]$ adds a new variable and assigns it as value the individual d. Cf. [2]).
[11] The universal quantifier is defined in terms of the existential quantifier and negation.

conceptualization are quite exceptional and should be strongly motivated by the context. In (4) above, for example, the shift is needed to preserve consistency and is suggested by the explicit introduction of some of the elements of the new conceptualization.

Slicing and the classical theory of quantification arise as a special case, namely when $CC = RC$, while RA and MS can be defined as derived notions:

$$\begin{array}{rll} \sigma[\exists x\phi]_{RA}\sigma' & \text{iff} & \cup_{c\in RC}\{\sigma[x/c]\}[\phi]\sigma'; \\ \sigma[\exists x\phi]_{SL}\sigma' & \text{iff} & \sigma[x/c][\phi]\sigma' \text{ for some } c \in RC; \\ \sigma[\exists x\phi]_{MS}\sigma' & \text{iff} & \sigma' = \cup_{c\in RC}\{\sigma'' \mid \sigma[x/c][\phi]\sigma''\}. \end{array}$$

I conclude by stating the other semantic clauses and the definition of support.[12]

Definition 5 [The Rest of the Semantics]

$$\begin{array}{rll} \sigma[Rt_1, ..., t_n]_a\sigma' & \text{iff} & \sigma' = \{i \in \sigma \mid < i(t_1), ..., i(t_n) > \in w_i(R)\}; \\ \sigma[\neg\phi]_a\sigma' & \text{iff} & \sigma' = \sigma - \{i \in \sigma \mid \exists\sigma'' : \sigma[\phi]_a\sigma'' \;\&\; i \leq \sigma''\}; \\ \sigma[\Diamond\phi]_a\sigma' & \text{iff} & \sigma' = \{i \in \sigma \mid \exists\sigma'' \neq \emptyset : \sigma[\phi]_a\sigma''\}; \\ \sigma[\phi \wedge \psi]_a\sigma' & \text{iff} & \exists\sigma'' : \sigma[\phi]_a\sigma''[\psi]_a\sigma'. \end{array}$$

Definition 6 [Support] $\sigma \models_a \phi$ iff $\exists\sigma' : \sigma[\phi]_a\sigma' \;\&\; \forall i \in \sigma : i \leq \sigma'$.

Conclusion

Since only definite subjects may constitute interpretations of variables, the problems of underspecification do not occur. At the same time, since even non-rigid conceptual covers may provide the quantificational domain, the overspecification problems are also avoided. More specifically, we are able to account for examples like (4) above that involve a shift of conceptualization within the same discourse, since different occurrences of quantifiers may range over different domains.

References

[1] D. Beaver, 'When variables don't vary enough', in: M. Harvey & L. Santelmann (eds), SALT 4, Cornell, 1994.

[2] P. Dekker, *Transsentential Meditations*, diss. University of Amsterdam, 1993.

[3] P. Dekker, 'Predicate Logic with Anaphora', in: M. Harvey & L. Santelmann (eds), SALT 4, Cornell, 1994.

[4] P. Dekker, 'On First Order Information Exchange', in: A. Benz & G. Jäger (eds), Mundial'97, München, 1997.

[5] J. van Eijck and G. Cepparello, 'Dynamic modal predicate logic', in: M. Kanazawa & C. Piñón (eds), *Dynamics, Polarity and Quantification*, CSLI, Stanford, 1994.

[6] J. Gerbrandy, 'Questions of Identity', this volume, 1997

[7] J. Groenendijk & M. Stokhof, 'Dynamic predicate logic', L&P, 1991.

[8] J. Groenendijk, M. Stokhof & F. Veltman, 'Coreference and modality', in: S. Lappin (ed.), *The Handbook of Contemporary Semantic Theory*, Blackwell, 1996.

[9] I. Heim, *The Semantics of Definite and Indefinite Noun Phrases*, PhD Thesis, University of Massachusetts at Amherst, 1982.

[10] I. Heim, 'On the projection problem for presupposition', in: M. Barlow et al. (eds), WCCFL2, 1983.

[11] H. Kamp, 'A theory of truth and semantic representation', in: J. Groenendijk et al., *Truth, interpretation and information*, Foris, 1981.

[12] F. Veltman, 'Defaults in update semantics', JPL, 1997.

[12] A possibility i survives in a state σ, $i \leq \sigma$ iff $\exists j \in \sigma$ such that j is the same as i except for the possible introduction of new variables. For a formal definition cf. [2].

A Modal Logic for Finite Graphs

Mario R. F. Benevides*†
Depart. Ciência da Computação - Instituto de Matemática†
Programa de Engenharia de Sistemas e Computação, COPPE*
Universidade Federal do Rio de Janeiro

1 Introduction

In this work we present a proof theory for a modal logic based on [BMdR96, BMV94], that is sound and complete with respect to finite directed graphs. We prove soundness and completeness using techniques used in Dynamic logic [Gol92, BdRV94] and in [BMdR96, BMV94]. We extend the language to a new modal system and show that it is sound and complete with respect to the class of undirected finite graphs. Finally, we investigate if some well known properties of undirected graphs are modally definable or not (e.g. planarity, coloring, Eulerian graph and etc.).

2 Finite Acyclic Directed Graphs

2.1 Language and Models

This section we present the language and define the notion of model and satisfaction.

Definition 2.1 *The* **direct graph language** *is a multi-modal language consisting of a set* Φ *of countably many propositional sysmbols (the elements of* Φ *are denoted by* p, q, *..), the booleans connectives* $\neg$ *and* $\wedge$ *and four modal operators:* $< i >$, $< a >$, $< i+ >$ *and* $< a+ >$, *and the formulas as defined as follows:*
$A ::= p \mid \top \mid \neg A \mid A_1 \wedge A_2 \mid < i > A \mid < a > A \mid < i+ > A \mid < a+ > A$

We freely use the standard boolean abbreviations $\vee$, $\rightarrow$ and $\leftrightarrow$ and also the following abbreviations for the duals: $[x]A := \neg < x > \neg A$ for $x \in \{i, a, i+, a+\}$.

Definition 2.2 *A* **finite direct graph** *is a tuple* $DG =< V, R_i, R_a, SI, SO >$ *where*
V *- is a finite set of vertex;*
SI *- is a nonempty subset of* V *which elements are called sinks;*
SO *- is a nonempty subset of* V *which elements are called sources;*
R_i *and* R_a *- are binary relations over* S, *i.e.,* $R_i, R_a \subseteq S \times S$
And the following conditions must be satisfied:
- R_i *and* R_a *are converse pairs of relations;*
- R_i *is conevrsely wellfounded (this means that theris no cycle).*
- for all elements $x \in S$, $x \in SI$ *if and only if there is no* $y \in S$ *such that* xR_iy;
- for all elements $x \in S$, $x \in SO$ *if and only if there is no* $y \in S$ *such that* yR_ix;

Definition 2.3 *A* **model** *for a diret graph language is a pair* $\mathcal{M} =< DG, \mathbf{V} >$, *where* DG *is a direct graph and* $\mathbf{V}$ *is a valuation function mapping vertex of the graph into sets of proposition symbols, i.e.,* $\mathbf{V} >: \Phi \longmapsto Pow(V)$.

The notion of satisfaction is defined as follows:

Definition 2.4 *Let $\mathcal{M} =< DG, \mathbf{V} >$ be a model. The notion of* **satisfaction** *of a formula A in a model $\mathcal{M}$ at a vertex v, notation $\mathcal{M}, v \models A$ can be inductively defined as follows:*

1. $\mathcal{M}, v \models p$ *iff* $v \in \mathbf{V}$
2. $\mathcal{M}, v \models \neg A$ *iff* $\mathcal{M}, v \not\models A$
3. $\mathcal{M}, v \models A \wedge B$ *iff* $\mathcal{M}, v \models A$ *and* $\mathcal{M}, v \models B$
4. $\mathcal{M}, v \models < i > A$ *iff there exists a* $w \in V$, $vR_i w$ *and* $\mathcal{M}, w \models A$
5. $\mathcal{M}, v \models < a > A$ *iff there exists a* $w \in V$, $vR_a w$ *and* $\mathcal{M}, w \models A$
6. $\mathcal{M}, v \models < i+ > A$ *iff there exists a* $w \in V$, $vR_i^+ w$ *and* $\mathcal{M}, w \models A$
7. $\mathcal{M}, v \models < a+ > A$ *iff there exists a* $w \in V$, $vR_a^+ w$ *and* $\mathcal{M}, w \models A$.

Where R_i^+ and R_a^+ denote the transitive closure of R_i and R_a respectively.

If $\mathcal{M}, v \models A$ for all vertex v, we say that A is valid in the model $\mathcal{M}$, notation $\mathcal{M} \models A$. And if A is valid in all model $\mathcal{M}$ we say that A is valid, notation $\models A$.

2.2 Proof Theory

The proof theory presented below is based in the one presented in [BMdR96, BMV94]. The axioms are all tautologies (1), the distribution axioms for the modalities i and a (2 and 3), the converse axioms for i and a (4 and 5), the Segerberg axioms (6,7,8 and 9), Löb axiom for i (10) and axioms for the constants *sink* and *source* (11 and 12). The inference rules are Modus Ponens, Universal Generalization and Substitution.

In order to make the proof theory presented below more elegant, some abbreviations are introduced for the reflexive and transitive closures and for some special constants:

$< i* > A := A \vee < i+ > A$ and its dual $[i*]A := \neg < i* > \neg A$;

$< a* > A := A \vee < a+ > A$ and its dual $[a*]A := \neg < a* > \neg A$.

$sink := [i]\bot$ and $source := [a]\bot$

Axioms

1. *All taltologies*
2. $[i](A \to B) \to ([i]A \to [i]B)$
3. $[a](A \to B) \to ([a]A \to [a]B)$
4. $A \to [i] < a > A$
5. $A \to [a] < i > A$
6. $[i+]A \leftrightarrow [i][*i]A$
7. $[i+](A \to [i]A) \to ([i]A \to [i+]A)$
8. $[a+]A \leftrightarrow [a][*a]A$
9. $[a+](A \to [a]A) \to ([a]A \to [a+]A)$
10. $[i+]([i+]A \to A) \to [i+]A)$

11. $< a* >$ *source*

12. $< i* >$ *sink*

Inference Rules

M.P. $A, A \rightarrow B/B$

U.G. $A/[i]A$ and $A/[a]A$

SUB. $A/\sigma A$
where σ is a map uniformely substituting formulas for propositional variables.

A formula A is said to be *theorem* of a set of formulas Γ, notation $\Gamma \vdash A$ iff there exists a sequence $A_0, A_1, ..., A_n$ of formulas such that A_i is either an axiom or was obtained by applying a inference rule to formulas of $\{A_0, A_1, ..., A_{i-1}\}$ and A is the last item A_n. We say that a set formula Γ is *inconsistent* iff $\Gamma \vdash \bot$ otherwise Γ is said to be *consistent*. A formula A is consistent iff $\{A\}$ is consitent.

2.3 Canonical Models

The canonical model construction is also the standard one [FL79, Gol92, BdRV94, BMdR96]. We first define the Fisher and Lander Closure $C_{FL}(\Gamma)$ for a set Γ of formulas and the atoms of $\Gamma At(\Gamma)$. And then prove the atom existence lemma.

A set of formulas Γ is said to be *closed under subformulas* iff for all $A \in \Gamma$, if B is a subformula of A then $B \in \Gamma$.

Definition 2.5 (**Fisher and Lander Closure**): *Let Γ be a set of formulas. The* **closure** *of Γ, notation $C_{FL}(\Gamma)$, is the smallest set of formulas satisfying the following conditions:*

1. *$C_{FL}(\Gamma)$ is closed under subformulas;*
2. *if $< i+ > A \in C_{FL}(\Gamma)$, then $< i > A \in C_{FL}(\Gamma)$*
3. *if $< i+ > A \in C_{FL}(\Gamma)$, then $< i >< i+ > A \in C_{FL}(\Gamma)$*
4. *if $< a+ > A \in C_{FL}(\Gamma)$, then $< a > A \in C_{FL}(\Gamma)$*
5. *if $< a+ > A \in C_{FL}(\Gamma)$, then $< a >< a+ > A \in C_{FL}(\Gamma)$*
6. *if $< i > \top$ and $< a > \top \in C_{FL}(\Gamma)$*
7. *$< i* >$ sink and $< a* >$ source $\in C_{FL}(\Gamma)$*
8. *if $A \in C_{FL}(\Gamma)$ and A is not of the form $\neg B$, then $\neg A \in C_{FL}(\Gamma)$.*

It is easy to verify that if Γ is a finite set of formulas, then the closure $C_{FL}(\Gamma)$ of Γ is also finite.

Definition 2.6 *Let Γ be a set of formulas. A set of formulas $\mathcal{A}$ is said to be an* **atom of** Γ *if it is a maximal consistent subset of $C_{FL}(\Gamma)$. The set of all atoms of Γ is donoted by $At(\Gamma)$.*

Lemma 2.1 *Let Γ be a set of formulas and $\mathcal{M}$ be the set set of maximal consistent set containing Γ. Then $At(\Gamma) = \{\Sigma \cap C_{FL}(\Gamma) \mid \Sigma \in \mathcal{M}\}$.*

Lemma 2.2 *Let Γ be a set of formulas. If $A \in C_{FL}(\Gamma)$ and A is consistent then there exists an $\mathcal{A} \in At(\Gamma)$ such that $A \in \mathcal{A}$.*

Lemma 2.3 *Let Γ be a set of formulas and $At(\Gamma) = \{\mathcal{A}_1, ..., \mathcal{A}_n\}$. Then $\vdash \bigwedge \mathcal{A}_1 \vee ... \vee \bigwedge \mathcal{A}_n\}$.*

Definition 2.7 *Let Γ be a set of formulas. The* **canonical model over** Γ *is a tuple $\mathbf{G}^\Gamma =< At(\Gamma), S_i^\Gamma, S_a^\Gamma, \mathbf{V}^\Gamma >$, where for all propositional symbols p and for all atoms $\mathcal{A}, \mathcal{B} \in At(\Gamma)$ we have*

- $\mathbf{V}^\Gamma(p) = \{\mathcal{A} \in At(\Gamma) \mid p \in \mathcal{A}\}$;
- $\mathcal{A}S_i^\Gamma\mathcal{B}$ *iff* $\bigwedge \mathcal{A} \wedge < i > \bigwedge \mathcal{B}$;
- $\mathcal{A}S_a^\Gamma\mathcal{B}$ *iff* $\bigwedge \mathcal{A} \wedge < a > \bigwedge \mathcal{B}$;

We say that $\mathbf{V}^\Gamma$ is the *canonical valuation* and S_i^Γ and S_a^Γ are the *canonical relations.* For the sake of clarity we avoid to use the Γ subscripts.

Lemma 2.4 *Let Γ be a set of formulas and $\mathcal{A} \in At(\Gamma)$. Then for all formulas $< i > A, < a > A \in C_{FL}(\Gamma)$ we have*

1. *$< i > A \in \mathcal{A}$ iff there exists $\mathcal{B} \in At(\Gamma)$ such that $\mathcal{A}S_i\mathcal{B}$ and $A \in \mathcal{B}$;*
2. *$< a > A \in \mathcal{A}$ iff there exists $\mathcal{B} \in At(\Gamma)$ such that $\mathcal{A}S_a\mathcal{B}$ and $A \in \mathcal{B}$*

Lemma 2.5 *(***Truth lemma***: Let $\mathbf{G}$ be a canonical model over Γ. For all atoms $\mathcal{A}$ and all $A \in C_{FL}(\Gamma)$, $\mathbf{G}, \mathcal{A} \models A$ iff $A \in \mathcal{A}$.*

Theorem 2.1 *The modal logic for direct graphs is sound and complete with respect to the class of finite canonical models.*

Our strategy now is to show that canonical models are graphs.

Lemma 2.6 *Let $\mathbf{G}$ be a canonical model over Γ and $SI_\Gamma = \{\mathcal{A} \in At(\Gamma) \mid sink \in \mathcal{A}\}$ and $SO_\Gamma = \{\mathcal{A} \in At(\Gamma) \mid source \in \mathcal{A}\}$. Then $SI_\Gamma \neq \emptyset$ and $SO_\Gamma \neq \emptyset$.*

Proof:

$< i* > sink, < a* > source \in C_{FL}$ by definition 2.5 (7), as C_{FL} is closed under subformula $sink, source \in C_{FL}$. Using lemma 2.2, there exists atoms $\mathcal{A}, \mathcal{B} \in At(\Gamma)$ such that $sink \in \mathcal{A}$ and $source \in \mathcal{B}$.

$\triangle$

Lemma 2.7 *Let $\mathbf{G}$ be a canonical model over Γ. Then S_i and S_a are converse pairs of relations. That is, for every $\mathcal{A}, \mathcal{B} \in At(\Gamma)$, $\mathcal{A}S_i\mathcal{B}$ iff $\mathcal{B}S_a\mathcal{A}$.*

Definition 2.8 *(***Path and Cycle***): Let $\mathbf{G}$ be a canonical model over Γ. A* **i-path** *Π_i is any sequence of atoms $\mathcal{A}_1, \ldots, \mathcal{A}_n$ such that $\mathcal{A}_1S_i\mathcal{A}_2 \ldots \mathcal{A}_{n-1}S_i\mathcal{A}_n$. A* **i-cycle** *is any path Π_i where $\mathcal{A}_1 = \mathcal{A}_n$.*

Theorem 2.2 *(***Aciclicity***): Let $\mathbf{G}$ be a canonical model over Γ. Then there is no i-cycle in S_i^Γ.*

Proof:

Suppose $\mathbf{G}$ has a i-cycle $\zeta_i = \mathcal{A}_1S_i\mathcal{A}_2 \ldots \mathcal{A}_{n-1}S_i\mathcal{A}_nS_i\mathcal{A}_1$. Then $\mathbf{G}$ admits an infinite i-path Π_i of the form:

$\Pi_i = \mathcal{A}_1S_i\mathcal{A}_2 \ldots \mathcal{A}_nS_i\mathcal{A}_1S_i\mathcal{A}_2 \ldots \mathcal{A}_nS_i\mathcal{A}_1 \ldots$

Let ϕ be any formula such that $\phi \in \mathcal{A}_2$.

By a simple semantical reasoning we know that $\mathbf{G}, \mathcal{A}_1 \models < i+ > \phi$, once there exists a path $\mathcal{A}_1S_i\mathcal{A}_2 \ldots \mathcal{A}_nS_i\mathcal{A}_1S_i\mathcal{A}_2$ and $\phi \in \mathcal{A}_2$.

Using the counter-positive of Löb's axiom and axiom 6 we get $\vdash < i+ > \phi \rightarrow < i+ > (\phi \wedge [i][i+]\neg\phi)$. *By soundness we should have* $\models < i+ > \phi \rightarrow < i+ > (\phi \wedge [i][i+]\neg\phi)$ *and therefore* $\mathbf{G}, \mathcal{A}_1 \models < i+ > (\phi \wedge [i][i+]\neg\phi)$. *But that means that there exists a point in the path* Π_i *where we have* ϕ *and all points ahead of this point we would have* $\neg\phi$, *but this is a contradiction once the path* Π_i *is a infinite seguence of repetions of the cycle* ζ_i *and* $\phi \in \mathcal{A}_2$. *So there is no such a point, and that is a contradiction. Therefore* **G** *cannot have a i-cycle.*

△

Analogously, we could state definitions to a-path and a-cycle. And it is trivial to prove that **G** has no a-cycle, once S_a and S_i are converse pairs of relations.

Corollary 2.1 *Let* **G** *be a canonical model over* Γ. *Then* **G** *is a finite acyclic direct graph.*

Proof:

G *is finite because* $At(\Gamma)$ *is finite. By the acyclicity theorem* **G** *is acyclic.*

G *satisfies all the conditions for a finite derect graph, i.e., it has a non-empty set of sinks and sources (lemma 2.6)* $SI_\Gamma \neq \emptyset$ *and* $SO_\Gamma \neq \emptyset$. S_i *and* S_a *are converse pairs of relations. And* S_i *is conversely wellfounded because every a-path is finite and* S_a *is the converse relation of* S_i.

△

Theorem 2.3 **(Completeness for finite direct graph)**: *The modal logic for direct graphs is complete with respect to the class of finite acyclic direct graph.*

Proof:

For every formula A we can build a canonical model $\mathbf{G}_A$, *by the existence lemma 2.2 there exist an atom* $\mathcal{A} \in At(A)$ *such that* $A \in \mathcal{A}$, *and by the truth lemma 2.5* $\mathbf{G}_A, \mathcal{A} \models A$. *Corollary 2.1 assures that* $\mathbf{G}_A$ *is a finite acyclic direct. Therefore, our modal system is complete with respect to finite acyclic direct graphs.*

△

The proof of soundness is also done in a standard fashion.

3 Undirected Graphs

Now, we extend the language with a new modality $\Box$ and proof that this new axiomatic is sound and complete with respect to the class of finite undirected graphs. The proof methodology is analogous to the one used in the previous section. We also prove that this modality also satisfies modal distribution, symmetry and universal generalization. We denote by **UG** the proof theory presented in section 2.2 plus the following definitions:

Definition 3.1 *Define:* $\Box A \leftrightarrow [i]A \wedge [a]A$

And its dual $\Diamond A := \neg\Box\neg A$

Theorem 3.1 $\vdash \Diamond A \leftrightarrow < i > A \vee < a > A$.

Theorem 3.2 *(***Distribution***): $\vdash \Box(A \to B) \to \Box A \to \Box B$.*

Theorem 3.3 *(***Symmetry***): $\vdash A \to \Box\Diamond A$.*

Theorem 3.4 *(***Universal Generalization***): The rule of Universal Generalization is a derived rule, i.e., $\vdash A / \vdash \Box A$.*

Theorem 3.5 *(***Completeness for finite undirect graph***): The modal logic for undirect graphs* **UG** *is complete with respect to the class of finite undirect graphs*[1].

4 Modal Definability

In this section, we investigate if some well known graph property are modally definable or not. Among this properties are: coloring, Eulerian graphs, Hamiltonians graphs and planarity. We show that planarity, Hamiltonian and Eulerian graphs are not modally definable. But in the case of coloring, we not only show that it is modaly definable as we provide a sound and complete axiomatization for it as a normal modal logic. Using our modal logic for undirected graphs we can abtain an axiomatization for planarity that is sound and complete w.r.t. to the class of planar graphs.

5 Conclusions

Acknowledgments

The author has received partial support from the Brazilian Research Agency CNPq and wishes to thank Yde Venema for discussions in early stages of the work. This article was written during his sabbatical leave at Institute for Logic Language and Computation ILLC in Amsterdam.

References

[BdRV94] P. Blackburn, M. de Rijke, and Y. Venema. *Modal Logic.* CWI, Amsterdam, 1994. Unpublished Manuscript.

[BMdR96] P. Blackburn, W. MeyerViol, and M. de Rijke. *A Proof System for Finite Trees.* Lecture Notes in Computer Science 1092. Springer-Verlag, Berlin, 1996. Computer Science Logic 95.

[BMV94] P. Blackburn and W. Meyer-Viol. *Linguistic, logic and Finite Trees.* Bulletin of the IGPL 2:2-29. Oxford Press, 1994.

[FL79] M. J. Fisher and R. F. Lander. Propositional dynamic logic of regular programs. *Journal of Computer and System Sciences*, 18, 1979.

[Gol92] R. Goldblatt. *Logics of Time and Computation.* CSLI Lecture Notes 7. CSLI, Stanford, 1992.

[vB83] J. van Benthem. *Modal Logic and Classical Logic.* Bibliopolis, Naples, 1983.

[1] It is important to notice that the class of finite undirect graphs that we are dealing with does not include reflexive graphs

Nonmonotonic Logic and Neural Networks*

Reinhard Blutner with Paul David Doherty
Humboldt University Berlin

Abstract

A puzzle in the philosophy of mind concerns the gap between symbolic and subsymbolic (neuron-like) modes of processing (e.g. Smolensky 1988). The aim of this paper is to overcome this gap by viewing symbolism as a high-level description of the properties of (a class of) neural networks. Combining methods of algebraic semantics and nonmonotonic logic, the possibility of *integrating* both modes of viewing cognition is demonstrated. The main results are (I) that certain activities of connectionist networks can be interpreted as *nonmonotonic inferences*, and (II) that there is a strict correspondence between the coding of knowledge in Hopfield networks and the knowledge representation in weight-annotated Poole systems. These results (a) show the usefulness of nonmonotonic logic as a descriptive and analytic tool for analyzing emerging properties of connectionist networks, (b) single out certain logical systems by giving them a "deeper justification", and (c) pave the way for using connectionist methods (e.g. "simulated annealing") in order to perform nonmonotonic inferences.

1 Introduction

There is a gap between two different modes of computation: the symbolic mode and the subsymbolic (neuron-like) mode. Complex symbolic systems like those of grammar and logic are essential when we try to understand the general features and the peculiarities of natural language, reasoning and other cognitive domains. On the other hand, most of us believe that cognition resides in the brain and that neuronal activity forms its basis. Yet neuronal computation appears to be numerical, not symbolic; parallel, not serial; distributed over a gigantic number of different elements, not as highly localized as in symbolic systems. Another aspect is that the brain is an adaptive system that is very sensitive to the statistical character of experience. Hard-edged rule systems are not suitable to deal with this side of behavior. A unified theory of cognition must overcome these gaps and must assign the proper roles to symbolic, neural and statistical computation (e.g. Smolensky 1988, 1996; Balkenius & Gärdenfors 1991).

The aim of this paper is to demonstrate that the gap between symbolic and neuronal computation can be overcome when we view symbolism as a high-level description of the properties of (a class of) neural networks. The important methodological point is to illustrate that the instruments of model-theoretic (algebraic) semantics and nonmonotonic logic may be very useful in realizing this goal. In this connection it is important to stress that the algebraic perspective is entirely neutral with respect to fundamental questions such as whether a "content" is in the head or is a platonic abstract entity (cf. Partee with Hendriks 1997, p. 18). Consequently, the kind of "psychologic" we pursue here isn't necessarily in conflict with the general setting of model-theoretic semantics.

Information states are the fundamental entities in the construction of propositions. In the next section we interpret information states as representing states of activations in a connectionist network. In section 3 we consider how activation spreads out and how it reaches, at least for certain types of networks, asymptotically stable output states. Following and extending ideas of Balkenius & Gärdenfors

*The research leading to this paper was funded in part by the Max-Planck-Gesellschaft. Many thanks to Birgit Ahlemeyer, Markus Steinbach and all our colleagues who provided valuable input.

1991, we show that the *fast dynamics* of the system can be described asymptotically as a nonmonotonic inferential relation between information states. Section 4 introduces the notion of weight-annotated Poole systems, and section 5 explains in which way these systems bring about the correspondence between connectionist and symbolic knowledge bases.

2 Information states in Hopfield networks

A neural network is a system of connected units ("neurons"). Each unit has a certain *working range of activity*. Let this be the set $\{-1, 0, +1\}$ (+1: maximal firing rate, 0: resting, −1: minimal firing rate). A possible state s of the system describes the activities of each neuron: $s \in \{-1, 0, +1\}^n$, with n = number of units. A possible *configuration* of the network is characterized by a *connection matrix* w. Hopfield networks are characterized by symmetric configurations and zero diagonals ($w_{ij} = w_{ji}$, $w_{ii} = 0$). The *fast dynamics* describes how neuron activities spread through that network. In the simplest case this is described by the following *update function*:

$$f(s)_i = \Theta \sum_j w_{ij} \cdot s_j \qquad (\Theta \text{ a nonlinear function}). \tag{1}$$

Let us interpret activations as indicating information specification: the activations +1 and −1 indicate maximal specification, the resting activation 0 indicates underspecification. Generalizing a notion introduced by Balkenius & Gärdenfors 1991, the set $S = \{-1, 0, +1\}^n$ of activation states can be partially ordered in accordance with their informational content:

$$s \geq t \text{ iff } s_i \geq t_i \geq 0 \text{ or } s_i \leq t_i \leq 0, \quad \text{for all } 1 \leq i \leq n \tag{2}$$

$s \geq t$ can be read as *s is at least as specific as t*. The poset $\langle S, \geq \rangle$ doesn't form a lattice. However, it can be extended to a lattice by introducing a set $\perp$ of *impossible activation states*: $\perp = \{-1, 0, +1, nil\}^n - S$, where *nil* designates the "impossible" activation of a unit. It can be shown that the extended poset of activation states $\langle S \cup \perp, \geq \rangle$ forms a DeMorgan lattice: Replace the former definition (2) of the informational ordering by the following:

$$s \geq t \text{ iff } s_i = nil \text{ or } s_i \geq t_i \geq 0 \text{ or } s_i \leq t_i \leq 0, \quad \text{for all } 1 \leq i \leq n \tag{3}$$

CONJUNCTION $\circ$ can be interpreted as *simultaneous realization* of two activation states, DISJUNCTION $\oplus$ as some kind of generalization. This fact enables us to interpret activation states as propositional objects ("information states").

3 Asymptotic updates and nonmonotonic inference

In general, updating an information state s may result in a information state $f \ldots f(s)$ that doesn't include the information of s. However, for the following it is important to interpret updating as specification. If we want s to be informationally included in the resulting update, we have to "clamp" s somehow in the network. A technical way to do that has been proposed by Balkenius & Gärdenfors 1991. Let f designate the original update function (1) and $\underline{f}$ the clamped one, which can be defined as follows (including iterations):

$$\begin{aligned} \underline{f}(s) &= f(s) \circ s \\ \underline{f^{n+1}}(s) &= f\left(\underline{f^n}(s)\right) \circ s \end{aligned} \tag{4}$$

Hopfield networks (and other so-called *resonance systems*) exhibit a desirable property: when given an input state s the system stabilizes in a certain state (it is of no importance here whether the dynamics is clamped or not). Thus, the following set of *asymptotic updates* of s is well-defined:

$$ASUP_w(s) = \left\{t\colon t = \lim_{n\to\infty} \underline{f^n}(s)\right\} \tag{5}$$

Under certain conditions (asynchronous, stochastic updates) the function

$$E(s) = -\sum_{i>j} w_{ij} \cdot s_i \cdot s_j \tag{6}$$

is a Ljapunov function (energy function) of the dynamic system (Hopfield 1982). This enables us to characterize the asymptotic updates of s as those specifications of s that minimize E:

$$ASUP_w(s) = \min_E(s) \tag{7}$$

The notion of asymptotic updates naturally leads to a nonmonotonic inferential relation (between information states):

$$s \mid\!\sim_w t \qquad \text{iff } s' \geq t \text{ for each } s' \in ASUP_w(s) \tag{8}$$

With the help of the equivalence (7), the usual traits of nonmonotonic consequence relations can be shown:

Supraclassicality:	if $s \geq t$, then $s \mid\!\sim_w t$	(9)
Reflexivity:	$s \mid\!\sim_w s$	
Cut:	if $s \mid\!\sim_w t$ and $s \circ t \mid\!\sim_w u$, then $s \mid\!\sim_w u$	
Cautious Monotonicity:	if $s \mid\!\sim_w t$ and $s \mid\!\sim_w u$, then $s \circ t \mid\!\sim_w u$	

This corresponds to results found by Balkenius & Gärdenfors 1991, who have considered information states for the case that they form a Boolean algebra.

4 Weight-annotated Poole systems

In connectionist systems knowledge is encoded in the connection matrix w (or, alternatively, the energy function E). Symbolic systems usually take a default logic and represent knowledge as a database consisting of expressions having default status. A prominent example of such a framework has been proposed by Poole (e.g. Poole 1988, 1996). In this section, we introduce a variant of Poole's systems, which we will call *weight-annotated Poole systems*. This variant will be proven to be useful for relating the different types of coding knowledge (see section 5).

Let us consider the language L_{At} of propositional logic (referring to the alphabet At of atomic symbols). A triple $T = \langle At, \Delta, g\rangle$ is called a *weight-annotated Poole system* iff (i) Δ is a set of consistent sentences built on the basis of At (the possible hypotheses); (ii) $g\colon \Delta \mapsto [0,1]$ (the weight function). A *scenario of a formula α in T* is a subset Δ' of Δ such that $\Delta' \cup \{\alpha\}$ is consistent. The *weight of a scenario* Δ' is

$$G(\Delta') = \sum_{\delta\in\Delta'} g(\delta) \; - \sum_{\delta\in(\Delta-\Delta')} g(\delta) \tag{10}$$

A *maximal scenario of* α *in* T is a scenario the weight of which is not exceeded by any other scenario (of α in T). With regard to a weight-annotated Poole system T, the following cumulative consequence relation can be defined:

$$\alpha \mathrel{\succ\!\!\sim}_T \beta \quad \text{iff } \beta \text{ is an ordinary consequence of each maximal scenario of } \alpha \text{ in } T \tag{11}$$

It is important to give a preference semantics for weight-annotated Poole systems. This preference semantics may be seen as the decisive link for establishing the correspondence between connectionist and symbolic systems.

Let v denote an ordinary (total) interpretation for the language L_{At} (v: $At \mapsto \{-1, 1\}$). The usual clauses apply for the evaluation of the formulas of L_{At} relative to v. The following function indicates how strong an interpretation v conflicts with the space of hypotheses Δ:

$$\mathfrak{E}(v) = -\sum_{\delta \in \Delta} g(\delta) \cdot [\delta]_v \quad \text{(call it the "energy" of the interpretation)} \tag{12}$$

An interpretation v is called a *model* of α just in case $[\alpha]_v = 1$. A *preferred model* of α is a model of α with minimal energy $\mathfrak{E}$ (with regard to the other models of α). As a semantic counterpart to the syntactic notion $\alpha \mathrel{\succ\!\!\sim}_T \beta$, let us take the following relation:

$$\alpha \mathrel{\succ\!\!\approx}_T \beta \quad \text{iff each preferred model of } \alpha \text{ is a model of } \beta \tag{13}$$

As a matter of fact, the syntactic and the semantic notions coincide. (A proof can be found in Blutner 1997).

5 The correspondence between Hopfield networks and weight-annotated Poole systems

Bringing about the correspondence between connectionist and symbolic knowledge bases, we have first to look for a symbolic representation of information states. Let us again consider the propositional language L_{At}, but let us now take this language as a symbolic means to speak about information states. Following usual practice in algebraic semantics, we can do this formally by interpreting (some subset of the) expressions of the propositional language by the corresponding elements of the DeMorgan algebra $\langle S \cup \bot, \geq \rangle$. More precisely, let us call the triple $\langle S \cup \bot, \geq, \rceil\ \lfloor \rangle$ a *Hopfield model* (for L_{At}) iff $\rceil\ \lfloor$ is a function assigning some element of $S \cup \bot$ to each atomic symbol and obtaining the following conditions: $\rceil \alpha \wedge \beta \lfloor = \rceil \alpha \lfloor \circ \rceil \beta \lfloor$; $\rceil {\sim}\alpha \lfloor = -\rceil \alpha \lfloor$ ("−" converts positive into negative activation and vice versa).

A Hopfield model is called *local* (for L_{At}) iff it realizes the following assignments: $\rceil p_1 \lfloor = \langle 1\ 0 \ldots 0 \rangle$, $\rceil p_2 \lfloor = \langle 0\ 1 \ldots 0 \rangle$, ..., $\rceil p_n \lfloor = \langle 0\ 0 \ldots 1 \rangle$. With regard to local Hopfield models each state can be represented by a conjunction of literals (atoms or their inner negation); e.g. $\langle 1\ 1\ 0 \rangle = \rceil p_1 \wedge p_2 \lfloor$, $\langle 1\ 1\ {-1} \rangle = \rceil p_1 \wedge p_2 \wedge {\sim}p_3 \lfloor$. In other words, in the case of local models each information state can be considered as symbolic.

Local Hopfield models give the opportunity to relate connectionist and symbolic knowledge bases in a way that allows to represent nonmonotonic inferences in neural (Hopfield) networks by inferences in weight-annotated Poole systems. The crucial point is the translation of the connection matrix w into an associated Poole system T_w. Let us consider a Hopfield system (n neurons) with connection matrix w, and let $At = \{p_1, \ldots, p_n\}$ be a set of atomic symbols. Take the following formulae α_{ij} of L_{At}:

$$\alpha_{ij} =_{def} (p_i \leftrightarrow sign\,(w_{ij})\; p_j) \qquad \text{for } 1 \leq i < j \leq n \tag{14}$$

For each connection matrix w the *associated Poole system* is defined as $T_w = \langle At, \Delta_w, g_w \rangle$, where the following clauses apply:

$$\text{a.} \quad \Delta_w = \{\alpha_{ij}\colon 1 \leq i < j \leq n\} \tag{15}$$
$$\text{b.} \quad g_w(\alpha_{ij}) = |\,w_{ij}\,|$$

Updating information states came out as a kind of specification in section 3. Under certain conditions (no isolated nodes) it can be shown that each (partial) information state is completed asymptotically. Consequently, $ASUP_w(s)$ contains only total information states. Together with the equivalence (7) and the definitions (12) & (13), this fact allows us to prove that nonmonotonic inferences based upon asymptotic updates can be represented by inferences in weight-annotated Poole systems:

Theorem

Assume any formulae α and β that are conjunctions of literals. Let the Poole system T be *associated* with the connection matrix w. Then

$$\rceil\alpha\lfloor \;\mid\!\sim_w\; \rceil\beta\lfloor \qquad \text{iff } \alpha \supset\!\!=_T \beta \quad (\text{iff } \alpha \supset\!\!-_T \beta).$$

This result shows that we can use nonmonotonic logic to characterize asymptotically how neuron activities spread through the connectionist network. In particular, a weighted variant of Poole's logical framework for default reasoning has proven to be useful. One possible application of the correspondence may be the use of connectionist techniques to perform nonmonotonic inferences ("simulated annealing", cf. Derthick 1990).

Finally, we should stress that our primary aim was a methodological one: the demonstration that model-theoretic semantics may be very useful for analyzing (emerging properties of) connectionist networks. Admittedly, the results found so far are much too simplistic to count as a real contribution to closing the gap between symbolism and connectionism. What is important, in our view, is to get an active dialog between the traditional symbolic approaches to logic, information and language and the connectionist paradigm. Perhaps, this dialog may shed new light on old notions like partiality, updates, underspecification, learning, genericity, homogeneity, salience, probabilistic logic, randomized computation, etc.

References

Balkenius, C. & Gärdenfors, P. (1991): "Nonmonotonic inferences in neural networks". In J.A. Allen, R. Fikes, & E. Sandewall (eds.), *Principles of knowledge representation and reasoning*. San Mateo, CA: Morgan Kaufmann.

Blutner, R. (1997): "Psychologic". Handout. Available as `http://www2.rz.hu-berlin.de/asg/blutner/psylogic.ps`.

Derthick, M. (1990): "Mundane reasoning by settling on a plausible model". *Artificial Intelligence* 46, 107–157.

Hopfield, J.J. (1982): "Neural networks and physical systems with emergent collective computational abilities". *Proceedings of the National Academy of Sciences* 79, 2554–2558.

Partee, B. with Hendriks, H.L.W. (1997): "Montague Grammar". In J. van Benthem & A. ter Meulen (eds.), *Handbook of Logic and Language*. Cambridge: MIT Press. 5–91.

Poole, D. (1988): "A logical framework for default reasoning". *Artificial Intelligence* 36, 27–47.

Poole, D. (1996): "Who chooses the assumptions?". In P. O'Rorke (ed.), *Abductive Reasoning*. Cambridge: MIT Press.

Smolensky, P. (1988): "On the proper treatment of connectionism". *Behavioral and Brain Sciences* 11, 1–23.

Smolensky, P. (1996): "Computational, dynamical, and statistical perspectives on the processing and learning problems in neural network theory". In P. Smolensky, M.C. Mozer, & D.E. Rumelhart (eds.), *Mathematical Perspectives on Neural Networks*. Mahwah, NJ: Lawrence Erlbaum Associates. 1–13.

The Relativization of Modals

Virginia Brennan
Vanderbilt University

The context relativity of modal semantics is formalized in Kratzer 1981, 1991b by means of two open parameters included in the semantics of any modal word: the MODAL BASE (the set of accessible worlds) and the ORDERING SOURCE (the world to which other worlds are compared to determine a similarity ordering). The values of the modal base and ordering source are determined by context-sensitive *functions* known as CONVERSATIONAL BACKGROUNDS. The idea is that the context specific information which determines whether a sentence such as 1 gets a deontic or an epistemic reading is funneled into the semantic interpretation *via* functions from worlds to sets of propositions; the intersection of the resulting set of propositions is the set of accessible worlds. (Something similar can be said for the ordering source, a mechanism Kratzer generalizes from its original application to the semantics of deontic modality (see Åqvist 1984) and conditionals and counterfactuals (Stalnaker 1968, 1970, Lewis 1973) to all modal expressions.)

1. John may leave early.
   epistemic: Possibly, John will leave early.
   deontic: It is allowed that John leaves early.

It is often assumed that discourse contexts are rich enough to supply the information needed to determine the value of the modal base and ordering source (as is evident from the terms *conversational background* (Kratzer 1981, 1991b) and *conversational information* (Groenendijk and Stokhof 1975)), but in fact how much of this background information actually is available in discourse contexts is something that varies a lot from discourse to discourse, often for reasons having to do with the structure of the text (*i.e.* having to do with issues such as topic-setting and foreshadowing).

In this paper, I investigate (i) how modal sentences get integrated into discourses, (ii) more specifically, how they get integrated into discourses when the value of the modal base is only partially determined, and (iii) to what extent and in what ways information relativizing the modal must be expressed or referred to in the discourse.

Using the framework set in place in Groenendijk, Stokhof and Veltman 1996,[1] I account for the underdetermination of the modal base as

[1] But with possible situations rather than possible worlds.

an instance of partial information regarding the identity of a discourse referent. Geurts 1995 and Portner 1996, to analyze modal subordination, treat conversational backgrounds as discourse referents, and I adopt that strategy here as well[2]; when the discourse does not establish the content of the modal base, as it will not in likely contexts for 2, interpretation proceeds in much the same way that it proceeds in cases where the identity of an individual is only partially determined, as in 3, where the indefinite triggers the introduction of a new discourse referent, but one that is only sketchily described.

2. I don't know why, but Anna must live in the city.
3. A man came in.

Groenendijk, Stokhof and Veltman 1996 define *possibilities* and *information states* as in 4 and 5 (although using worlds rather than situations)[3].

4. Let D, the domain of discourse, and S, the set of possible situations, be two disjoint non-empty sets. The POSSIBILITIES based on D and S are the set I of triples $\langle r,g,s \rangle$, where r is a referent system, g is an assignment function, and $s \in S$.

5. Let I be the set of possibilities based on D and S. The set of INFORMATION STATES based on I is the set J such that $j \in J$ iff $j \subseteq I$ and $\forall i,i' \in j$: i and i' have the same referent system.

Thus, an information state consists of possibilities which agree on the assignment of discourse referents to variables but may differ with respect to the value assigned to discourse referents by the assignment function and/or the situation with respect to which propositions are evaluated.

This framework allows me to define modal bases, the possibility operator and the necessity operator as in 6-8.

---

[2] My motivation for treating conversational backgrounds (modal bases and ordering sources) as discourse referents is in part to be able to model the discourse semantics of modal propositions; another reason, explored in Brennan 1997, is because of the extensive similarities between modal bases and Reinhart's 1981 TOPICS and her analysis of the theoretical status of topics.

[3] A REFERENT SYSTEM is a mapping from variables to discourse referents (or PEGS, in the terms of Groenendijk, Stokhof and Veltman 1996).

6. A PROPOSITION-LEVEL MODAL BASE[4] is an expression of type <s,t>.
Given a model <S,D,M>, where S is the set of situations, D is the domain of discourse and M is the interpretation function, and a proposition-level modal base, α: $M(\alpha) = g(\alpha)$.

7. If ◊ is the S-scope possibility operator, then for any proposition-level modal base, α, and any proposition, _, and any possibility, i, the denotation of ◊ in i is as follows:

$$i(\Diamond(\alpha)(\_)) = 1 \text{ iff } \exists s', s' \in g(\alpha), \text{ such that } s' \in (\_).$$

8. If o is the S-scope necessity operator, then for any proposition-level modal base, α, and any proposition, _, and any possibility, i, the denotation of o in i is as follows:

$$i(o(\alpha)(\_)) = 1 \text{ iff } \forall s', s' \in g(\alpha), s' \in (\_).$$

Modal propositions have the same effect on the current information state as any other proposition: possibilities which are incompatible with the new proposition are eliminated. Even in discourses where the content of the modal base, α, is completely underdetermined, modal sentences are informative: if $g(\alpha)$ is incompatible with the scope of the modal (for possibility sentences) or if $g(\alpha)$ doesn't entail the scope of the modal (for necessity sentences) then any possibility i with g as the assignment function is eliminated from the information state. In this, the present account departs from Groenendijk, Stokhof and Veltman 1996, where the possibility sentences which are compatible with the current information state have no updating effect on it.

The preceding accounts for the limiting case, where the content of the modal base is completely underdetermined, and also allows for cases where its content is determined to some degree or other. Three phenomena suggest that the content of the modal base is always at least partially determined. The first is the failure of discourses such as 9, first discussed in Hintikka 1962; alongside this example, it is important to note that there are superficially similar but successful discourses such as 10.

---

[4] The definitions specify that the modal base in question is proposition-level because in related work I also define property-level modals and modal bases. See Brennan 1997.

9. It's raining. #But maybe it's not raining.
10. Elizabeth isn't dancing. But she could be.

If we assume for epistemic modality that assertions made in the immediately preceding discourse systematically help make up the content of the modal base, 9 is ruled out because it is contradictory. A dynamic or circumstantial modal base for *could*, in 10, in contrast, need not include the content of all recently asserted propositions.

The second phenomenon relevant here is MODAL SUBORDINATION, first discussed by Roberts (see Roberts 1989, 1996a). Modal subordination, which occurs in discourses in which an anaphor in a modal sentence takes as its antecedent an expression which is embedded in a preceding modal sentence, is illustrated by 11; 12, from Geurts 1995, illustrates the fact that modal subordination isn't always possible.

11. A thief might break into the house. He would take the silver.
12. Theo can balance a banana on the tip of his nose. #He may eat it.

Modal subordination, in a certain light, concerns the opposite state of affairs from what we saw in 9-10: whereas 9 showed that discourses fail in case certain propositions make it into the modal base, 12 shows that discourses can fail in case certain propositions *don't* make it into the modal base. (This general idea about what is at issue in modal subordination is worked out in different ways in Roberts 1989, 1996a, Geurts 1995, and Portner 1996.)

Examples such as 13 also indicate that modal bases can't be completely undefined.

13. I can't tell you why, but it must be raining.

There are felicitous readings of this sentence: for example, the bouletic sense is 'I can't tell you why I want this so much, but it is necessary that it be raining if my wishes are to be fulfilled!' and the deontic sense is 'I can't tell you why this is required, but it is required that it be raining (that day, or if we are to leave early, etc.)'. 13, however, cannot be read this way: I can't tell you the kind of necessity involved (bouletic, deontic, epistemic), but in some sense, it is necessary that it be raining.

What we've seen is that while modal bases can in principle be completely underdetermined in content, they are in fact normally assigned some content. The pressing question then becomes this: How do hearers decide on the content for the modal base? We have a start on the answer from what we observed regarding 13: Evidently, modal sentences may be interpreted even in the absence of content for the modal base, but not without some notion of the character of the modal base. To interpret 13 at all, the claim is, speakers and hearers must decide on a type of modality (bouletic, deontic, epistemic, etc.), and in this sense, modal bases are never be completely undefined. Often, the type of modality is indicated by means of an adverb or adjunct, such as those in 14.

14. Legally/As far as they are concerned/In view of what the law provides, he may wait until Thursday.

The adverb or adjunct in cases such as this serves as a 'title' for the modal base, as it were, indicating the sort of proposition it must denote. Formally we can incorporate this constraint on the felicity of modal utterances by assuming that all modal propositions are conjunctions semantically: in the first conjunct, a sentence adverbial takes the modal base as its argument; the second conjunct is the modal operator headed clause seen earlier in 7 and 8. This idea is sketched in the semantic rules for modals in 15 and 16.

15. $i(\Diamond(\alpha)(\_)) = 1$ iff $ADV(\alpha)$ & $\exists s', s' \in g(\alpha)$, such that $s' \in (\_)$.

16. $i(o(\alpha)(\_)) = 1$ iff $ADV(\alpha)$ & $\forall s', s' \in g(\alpha), s' \in (\_)$.

For 14, the added conjunct in 15 will ensure that the content of the modal base restricting *may* will be a proposition expressing what the relevant laws provide. The adverbial, ADV, may or may not occur overtly in the discourse, but what we've observed is that some such expression must at least be understood.

Beyond this sort of determination of the 'title' of the modal base, α, its content (the value of $g(\alpha)$) may or may not be determined in the discourse, as we've seen. Discourses such as 9 and 12 demonstrate that there is some systematicity to the determination of α's content. In the remainder of the paper, I review observations and proposals regarding how the content of α is determined, and argue that it may be both underdetermined (empty of any content other than its adverbial 'title') and overdetermined (so that the scope of the modal simply repeats the modal base) for reasons having to do with the structure of the text.

REFERENCES

Åqvist, L. 1984 "Deontic Logic" in Gabbay, D. and F. Guenthner, eds. *Handbook of Philosophical Logic, Vol. II Extensions of Classical*

Logic, pp. 605-714 (Dordrecht: Reidel).
Brennan, V. 1997 *Modalities*, ms. Vanderbilt University.
Geurts, B. 1995 *Presupposing,* University of Stuttgart doctoral dissertation, Universität Osnabrück, FB 7 49069 Osnabrück.
Groenendijk, J. and M. Stokhof 1975 "Modality and Conversation" in *Theoretical Linguistics* 2.61-112.
Groenendijk, J., M. Stokhof and F. Veltman 1996 "Coreference and Modality" in S. Lappin, ed. *Handbook of Contemporary Semantic Theory*, pp. 179-213 (Oxford and New York: Blackwell).
Hintikka, J. 1962 *Knowledge and Belief* (Ithaca, NY: Cornell).
Kratzer, A. 1981 "The Notional Category of Modality" in H.J. Eikmeyer and H. Rieser, eds. *Words, Worlds and Contexts: New Approaches in Word Semantics* (Berlin: Walter de Gruyter).
_____ 1991a "Conditionals" in A. von Stechow and D.Wunderlich, eds. Semantics: An International Handbook of Contemporary Research (Berlin/NY: Walter de Gruyter).
_____ 1991b "Modality" in von Stechow and Wunderlich, eds.
Lewis, D. 1973 *Counterfactuals* (Cambridge, MA: Harvard U. Press).
Portner, P. 1996 "Modal Discourse Referents and the Semantics-Pragmatics Boundary" in V. Miglio, ed. *University of Maryland Working Papers in Linguistics* (College Park, MD).
_____ 1997 "The Semantics of Mood, Complementation and Conversational Force" in *Natural Language Semantics* 5.167-212.
Reinhart, Tanya 1981 "Pragmatics and Linguistics: An Analysis of Sentence Topics" in *Philosophica* 27.1.53-94.
Roberts, C. 1989 "Modal Subordination and Pronominal Anaphora in Discourse", in *Linguistics and Philosophy* 12. 683-721.
_____ 1996a "Anaphora in Intensional Contexts" in Lappin, S., ed., pp. 215-246.
_____ 1996b "Information Structure in Discourse: Towards an Integrated Formal Theory of Pragmatics" in *Ohio State University Working Papers in Linguistics, No. 49 Papers in Semantics*, pp. 91-136 (Columbus, Ohio: Ohio State Linguistics Department).
Stalnaker, Robert 1968 "A Theory of Conditionals" in Rescher, N., ed. *Studies in Logical Theory* (Oxford: Basil Blackwell).
_____ and Richmond Thomason 1970 "A Semantic Analysis of Conditional Logic" *Theoria* 36.23-42.
Stump, G. 1985 *The Semantic Variability of Absolute Constructions* (Dordrecht: Reidel).

A Logic of Vision

Michiel van Lambalgen
& Jaap van der Does

Abstract

In this note we present a logic of vision which employs conditional quantifiers, a new form of generalised quantification. We indicate how the logic provides for a semantics of direct perception reports.

The logic of vision is resource bounded, where the resources consist of frames over sets of assignments. Conditional quantifiers use such frames to filter the information given by a formula. This kind of filtering has interesting logical characteristics in common with the blurring of reality that figures in describing perception.

It is a general feature of resource bounded logics that the underlying logics are weak, but that stronger principles can be obtained pragmatically, by strengthening the resource. For the logic of vision this feature is clarified by showing how changes in the resource capture different notions of partiality, and by studying how the perception verb interacts with quantificational NPs in different visual contexts. The inference Veridicality, which does not hold generally, will receive our attention as well.[1]

1 At the beach

To clarify what is at stake, let us follow Jack to a seaside resort, where he is a lifeguard in his spare time. At first Jack is sitting in his observation post, from which he can see all boys and recognise them as such. After a short while a boy gets in danger. So Jack runs to the seashore, where he does not see all boys but does recognise the boys that he sees, among which the unhappy one. A sudden wave almost drowns Jack, but his colleagues manage to rescue him (and the boy). As soon as they have dragged Jack into a helicopter, Jack has all boys within eyeshot again, but the water in his eyes precludes him to identify them precisely. Under these circumstances, what is the logical relationship between (1) and (2)?

(1) Jack saw a boy swim (narrow scope existential).

(2) A boy is such that Jack saw him swim (wide scope existential).

The logic of vision does not give a single answer; it holds that an answer depends on the available perceptual resources. To show this in some detail, we first have to introduce one of its main ingredients: conditional quantification.

2 Conditional quantification

As Jack's heroic attempts indicate, the most important issues for a logic of vision are to specify the rôles of approximation and partiality. The relation between these concepts is given by the insight that a field of vision does two things: (i) it determines a part of reality corresponding to what is seen, and (ii) it determines a filter through which this part is seen. In the paper reality appears as a 'regulative ideal': it is an inverse limit of first order models (this allows, among other things, for a rich notion

1. The work presented is part of a much larger project, in which we use Marr's cognitive theory (cf. Marr 1982) to develop a logic of vision. This research is part of the PIONIER-project 'Reasoning with Uncertainty' sponsored by the Netherlands Organisation for Scientific Research (NWO) under grant PGS 22–262. The full paper can be obtained from: `http:/turing.wins.uva.nl/~jvddoes/`.

of intensional object). For simplicity it is just a first order model here. The filtering of this model is formalised by conditional quantification.

What does it mean to say that information is *conditionalised* or *filtered*? To answer this question we first introduce in general terms how perceptual information is structured.

Definition 2.1 A *pseudolattice* L is a partially ordered set in which meets and joins of finite non-empty sets exist. (Hence L need not have top or bottom.) A pseudolattice L is an *evidential* $\vee, \bigwedge$*-frame* if it is closed under arbitrary non-empty meets, such that the following distributive law holds: $a \vee \bigwedge_I b_i = \bigwedge_I (a \vee b_i)$.

In the logic of vision information is given as subsets of the set $|\mathcal{M}|^{\text{VAR}}$ of assignments for a first order model $\mathcal{M}$. Often, but not always, these sets are defined by formulas φ: $[\varphi]_\mathcal{M} := \{f \in |\mathcal{M}|^{\text{VAR}} : \mathcal{M}, f \models \varphi\}$. Conditional quantifiers filter information using evidential frames over sets of assignments.

Definition 2.2 Let $\mathcal{G}$ be an evidentials frame generated by sets of assignments. $\exists(\bullet|\mathcal{G})$, the *existential quantifier conditional on* $\mathcal{G}$, is the unique mapping **Form** $\longrightarrow$ $\mathcal{G}$ satisfying the Galois correspondence:

$$\varphi \subseteq C \text{ if and only if } \exists(\varphi|\mathcal{G}) \subseteq C,$$

for all $C \in \mathcal{G}$. Note: the Galois correspondence implies that $\exists(\varphi|\mathcal{G})$ must be defined as $\bigwedge\{C \in \mathcal{G} | \varphi \subseteq C\}$, *when the meet exists in* $\mathcal{G}$. In general, however, $\exists(\bullet|\mathcal{G})$ will be a partial map from **Form** to $\mathcal{G}$.

Conditional quantifiers no longer treat variables as mere placeholders! Since a frame $\mathcal{G}$ consists of sets of assignments, $\exists(\varphi|\mathcal{G})$ may depend on other variables that just the free ones in φ. Also, whether or not the quantifier binds any of the free variables in φ varies with the nature of $\mathcal{G}$. The reader may wish to check that a quantifier $\exists(\bullet|\mathcal{G})$ conditional on an evidential frame satisfies the following properties, *provided* $\exists(\bullet|\mathcal{G})$ is defined for the relevant formulas.

1) $\varphi \subseteq \psi$ implies $\exists(\varphi|\mathcal{G}) \subseteq \exists(\psi|\mathcal{G})$ (partial monotonicity);
2) $\varphi \subseteq \exists(\varphi|\mathcal{G})$ (partial coarsening);
3) $\exists(\varphi \vee \psi|\mathcal{G}) = \exists(\varphi|\mathcal{G}) \vee \exists(\psi|\mathcal{G})$ (partial additivity);
4) $\exists(\varphi \wedge \psi|\mathcal{G}) = \exists(\varphi|\mathcal{G}) \wedge \psi$ where $\psi \in \mathcal{G}$ ('taking out what is known').

Also, for $\mathcal{G}$ an evidential subframe of **Form**, $\exists(\mathbf{0}|\mathcal{G})$ will be defined if $\mathcal{G}$ is non-empty. But it could be different from $\mathbf{0}$, which may not be in $\mathcal{G}$.

Generalised quantification. We show that the existential quantifier is the same as the quantifier $\exists(\bullet|\mathcal{G}_x)$ with $\mathcal{G}_x$ generated by sets $\{f \in \mathcal{F} : \mathcal{M}, f \models \varphi\}$ where x does not occur free in φ. The inclusion $\exists(\varphi|\mathcal{G}_x) \subseteq \exists x\varphi$ is immediate from the Galois correspondence for $\exists(\bullet|\mathcal{G}_x)$. As to the converse inclusion, $\varphi \subseteq \exists(\varphi|\mathcal{G}_x)$ because $\exists(\varphi|\mathcal{G}_x) \in \mathcal{G}_x$. But all sets in $\mathcal{G}_x$ are closed under the relation between assignments differing at most at x. This is true in particular of $\exists(\varphi|\mathcal{G}_x)$, so $\exists x\varphi \subseteq \exists(\varphi|\mathcal{G}_x)$. Hence $\exists(\bullet|\mathcal{G})$ is truly a generalised quantifier; also because for certain $\mathcal{G}$ $\exists(\bullet|\mathcal{G})$ is not first order definable.

Blurred reality. Conditional quantifiers 'blur' reality: $\varphi \subseteq \exists(\varphi|\mathcal{G})$ as soon as $\exists(\varphi|\mathcal{G})$ is defined. A crucial notion of blurring is based on fields of vision as rough (homomorphic) images of reality. A model $\mathcal{N}$ is a *homomorphic image* of $\mathcal{M}$, iff there is a surjection h from $|\mathcal{M}|$ onto $|\mathcal{N}|$ such that: $R^\mathcal{N}(h(a_1), \ldots, h(a_n))$ if $R^\mathcal{M}(a_1, \ldots, a_n)$. Assign to each f for $\mathcal{M}$, $h(f)$ for $\mathcal{N}$ by $h(f)(x) := h(f(x))$, and consider

$$h^{-1}(\varphi^\mathcal{N}) := \{f \in |\mathcal{M}|^{\text{VAR}} : \mathcal{N}, h(f) \models \varphi\}$$

Then for positive φ: $\varphi^\mathcal{M} \subseteq h^{-1}(\varphi^\mathcal{N})$. Consequentely, the quantifier $\exists(\bullet|\mathcal{G}_n)$, with $\mathcal{G}_n$

the frame generated by $\{h^{-1}(\varphi^{\mathcal{N}}) : \varphi \textit{ positive}\}$, will often have a genuine blurring effect. Notice, by the way, that fields of vision as homomorphic images are rather different from the partial submodels used in situation semantics (Barwise 1981, Kamp 1984).

Below we encounter other ways in which a frame can filter the information given by a formula, but first we discuss how conditional quantification figures in the description of perception.

3 The logical form of perception reports

The logic of vision sustains a natural distinction between directly and indirectly perceived objects. A *directly* perceived object is represented by a free variable, which can only be 'measured' with finite precision; the degrees of precision being given by conditional quantifiers $\exists(\bullet|\mathcal{G})$. Instead, '*indirectly*' perceived objects are represented by means of bound variables. Some examples should clarify the distinction.

(3) 'I see this arm.' becomes: $\exists(A(x)|\mathcal{G}_I)$.

Here, the demonstrative 'this' is interpreted as the variable x, which receives its value from a contextually given assignment. So, x corresponds with the arm perceived directly, and the frame $\mathcal{G}_I$ with the filter of the speakers's perceptual field.

There are two ways to interpret proper names. Firstly, one may interpret (4) with a demonstrative element as: 'this object I see is Sharon'. Formally this corresponds to having a free variable in the representation, as in (4).

(4) 'I see Sharon.' becomes: $\exists(x = s|\mathcal{G}_I)$.

The constant s, for Sharon, denotes an object in reality. Secondly, one may read (4) indefinitely as: 'an object I see is Sharon', as in (5).

(5) $\exists x\exists(x = s|\mathcal{G}_I)$.

In what follows, we shall often use the open form. Here are some further examples:

(6) 'I see a boy' becomes: $\exists x\exists(B(x)|\mathcal{G}_I)$; and

(7) 'I see a boy swim' becomes: $\exists(B(x) \wedge S(x)|\mathcal{G}_I)$ or $\exists x\exists(B(x) \wedge S(x)|\mathcal{G}_I)$.

An example of a report with an indirectly perceived object is (8).

(8) 'I saw Jack consult a doctor.' becomes: $\exists(x = j \wedge \exists y[D(y) \wedge C(x,y)]|\mathcal{G}_I)$.

The examples indicate that the semantics for perception reports describing objects is similar to those describing scenes; mainly the descriptive content within the scope of 'to see' varies (cf. Hintikka 1969).

It should be noticed that in all the examples the perception operator has an open statement within its scope; some of the objects described must be seen directly. This is crucial, for a frame $\mathcal{G}$ acts trivially on 'closed' truths or falsities; $\exists(\mathbf{1}|\mathcal{G}) = \mathbf{1}$ and $\exists(\mathbf{0}|\mathcal{G}) = \mathbf{0}$. From this we also see that substitution may fail

$$x = t \ \& \ \exists(\varphi(x)|\mathcal{G}) \not\Rightarrow \exists(\varphi(t)|\mathcal{G}),$$

with t a constant or a variable. Similar effects occur in case of the following inferences which are often studied for perception reports.

4 The resource bounded logic of perception reports

Veridicality Since conditional quantifiers have a blurring effect, veridicality may fail to hold. Assume for instance that the nonempty set of swimmers $S(x)$ is properly contained in the set of people $P(x)$. Let Jack's frame be the extremely poor $\mathcal{G}_j = \{P(x)\}$. Then: $\exists(S(x)|\mathcal{G}_j) = P(x)$. So clearly $\exists(S(x)|\mathcal{G}_j)$ need not imply $S(x)$. There are, however, circumstances where veridicality *does* hold; e.g, if $S(x) \in \mathcal{G}_j$.

In the paper Veridicality is treated as a nonmonotonic principle, which captures the expectation that what we actually perceive continues to hold under refinement of perceptual information. It is proved that all positive formulas are veridical in this sense.

Partial Perception Perhaps the first requirement for an analysis of 'see' is that it should be able to cope with reports of the following kind, employing NPs, infinite VPs, and PPs:

$$\frac{\text{Whitehead saw Russell} \quad \text{Russell winked}}{\text{Whitehead saw a winking man}}$$

$$\frac{\text{Whitehead saw Russell} \quad \text{Russell winked}}{\text{Whitehead saw Russell wink}}$$

$$\frac{\text{Whitehead saw Russell} \quad \text{Russell had his shirt unbuttoned}}{\text{Whitehead saw Russell with his shirt unbuttoned}}$$

The common feature of these invalid inferences is that the sentence 'Whitehead saw Russell' refers to a visual image of reality, whereas the factual statements are true in reality itself. In particular, these models may be incomparable with each other—e.g., if Whitehead saw Russell from behind—or reality may be a refinement of a visual field but still the distance between Whitehead and Russell could have been too large for Whitehead to actually see—e.g., that Russell had his shirt unbuttoned. We sketch how different forms of partiality can be formalised using different kinds of frames.

The semantics of '*w saw* φ', φ positive, is given as $\exists(\varphi|\mathcal{G}_w)$, with $\mathcal{G}_w$ a suitable frame assigned to perceiver w. Note that $\exists(x = r \wedge W(x)|\mathcal{G}_w)$ says that it is *consistent* with the information available to Whitehead that Russell winks. This would also be the case, for instance, if $\exists(x = r \wedge W(x)|\mathcal{G}_w)$ equals the full set of assignments, i.e., when no nontrivial element of $\mathcal{G}_w$ dominates $x = r \wedge W(x)$. Clearly, one would not call this 'seeing'. Indeed, if the quantifier is conditional on an evidential frame lacking a top element, it is *un*defined for this case, as it is only defined when it represents nontrivial information.

In order to model the nonvalidity of the above inferences, it is elegant, although not strictly necessary, to import one more form of partiality into the conditional quantifiers. Suppose $\mathcal{M}_w$ represents Whitehead's approximation of the world, which contains two individuals: a_w and r_w, approximations of the 'real' individuals a and r, respectively. Suppose furthermore that we have only one predicate, W for 'wink'. The evidential frame $\mathcal{G}_w$ could then be taken to be generated by

$$\{\emptyset\} \cup \{\{f : \mathcal{M}_w, h_w(f) \models W(x)\} : x \text{ a variable}\}.$$

Now suppose that, although both a and r may actually be winking, Whitehead is only in a position to see a winking. This can be modelled by switching to a different evidential frame: introduce a predicate W' such that $\mathcal{M}_w \models W'(a_w)$, $W'(r_w)$ undefined, and let $\mathcal{G}'_w$ be defined as $\mathcal{G}_w$, except that we use W' instead of W. If we now compute $\exists(W(x) \wedge x = r|\mathcal{G}'_w)$, we see that there is no element of $\mathcal{G}'_w$ lying above $\{f : \mathcal{M}_w, h_w(f) \models W(x) \wedge x = r\}$, whence $\exists(W(x) \wedge x = r|\mathcal{G}'_w)$ is undefined, as desired.

It is important to observe that we need *not* actually change anything to the signature of $\mathcal{M}_w$; we may just take $\mathcal{G}'_w$ to consist of suitable subsets of elements of $\mathcal{G}_w$ and leave $\mathcal{M}_w$ unchanged. Hence, unlike in situation semantics, partiality is not introduced for the first order language; it resides in the conditionally quantified formulas. In fact, for suitable choices of frames conditional quantifiers can recapture the homomorphic image $\mathcal{M}_w$; but conditional quantification is *more general* in the sense that it allows one to formalise several forms of partiality simultaneously, using different kinds of frames.

We conceive of the relationship between approximating models and filters in the following manner. The basic idea is that perception must be viewed as some form of filtering of reality $\mathcal{M}$. Part of the filtering consists of the inevitable blurring imposed upon us by our perceptual apparatus; this is formally captured by the homomorphic images $\mathcal{M}_w$. (In the paper, part of a system $\langle \mathcal{M}_s, h_{st} \rangle_{s,t \in T}$ of first order models which has $\mathcal{M}$ as inverse limit.) Additional filtering occurs because of restricted perceptual fields and the effect of perspective. This is not part of the perceptual apparatus, neither is it a property of reality; it arises as a consequence of 'being in the world', hence it is put in the filters only. Very roughly speaking, $\mathcal{M}_w$ is concerned with the possible structuring of experience, i.e., concepts, whereas the filters $\exists(\bullet|\mathcal{G}_w)$ relate to actual experience, i.e., perception.

Quantifier principles Let us go back to the seaside to see what happens to Jack's logic of vision as he tries to save the poor boy's life; in particular: what happens to the logical relationships between (1) and (2)?

Case (a) 'Jack recognises a boy when he sees one, and he can see all boys.' Formally this means: $B(x) \in \mathcal{H}$. Since $\exists(\bullet|\mathcal{H})$ is the identity on the elements of $\mathcal{H}$, $B(x) \in \mathcal{H}$ is a veridicality assumption for the nominal argument. Indeed, in this case (1) is equivalent with (2) by 'taking in what is known':

$$\exists x[B(x) \wedge \exists(S(x)|\mathcal{H})] = \exists x[\exists(B(x) \wedge S(x)|\mathcal{H}).$$

Case (b) 'Jack recognises a boy when he sees one, but he might not see all boys'; i.e., $B(j,x) \in \mathcal{H}$, where $B(j,x) \subseteq B(x)$ restricts the boys to those in Jack's perceptual field. Then logic of vision predicts that (2) implies (1), but not conversely. To show the implication, first obtain

$$\exists x[B(j,x) \wedge \exists(S(x)|\mathcal{H})] = \exists x \exists(B(j,x) \wedge S(x)|\mathcal{H})$$

as in case (a). By weak monotonicity and the fact that $\exists$ is MON$\uparrow$

$$\exists x[B(j,x) \wedge \exists(S(x)|\mathcal{H})] \subseteq \exists x \exists(B(x) \wedge S(x)|\mathcal{H}).$$

It is worthwhile to notice that $B(x)$ is imported into the scope of $\exists(\bullet|\mathcal{H})$. This may seem surprising; couldn't it be the case that there is a boy whom Jack perceives as swimming, without actually being aware that it is *he* who swims? No, because the anaphor *him* in (2) is taken to imply that the boy is imported in Jack's visual field; since he correctly identifies boys, the conclusion follows. That the converse implication fails can be shown as under case (c).

Case (c) 'Jack can see all boys, but he cannot identify them precisely.' We show that in this case (1) and (2) are independent of each other, as we think they should be.

For a start we show that one of Jack's colleagues in the helicopter cannot infer (1) from (2). Given Jack's poor shape there may be boys swimming within his eyesight, but Jack need not perceive them. To show this formally, choose a model $\mathcal{M}$ as in figure 1 (all areas nonempty), and let Jack only discern between humans and the empty property: $\mathcal{H} := \{H(y), \mathbf{0}\}$. Jack's visual resources are too poor to discern boys: $B(y) \notin \mathcal{H}$! Under these unfortunate circumstances: $\exists(S(y)|\mathcal{H}) = H(y)$, and hence (2) is true. But $B(y) \wedge S(y) = \mathbf{0}$, whence $\exists(B(y) \wedge S(y)|\mathcal{H}) = \mathbf{0}$; (1) is false.

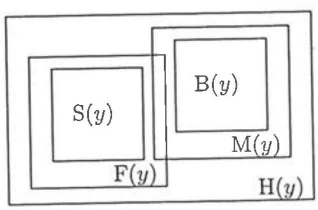


Figure 1: *Boys don't swim, but some men have fun.*

The direction from (1) to (2) should be invalid, too, because what appears to be a boy to Jack need not actually be one. This is a point where it is crucial to have evidential frames; the inference *is* valid for each $\mathcal{H}$ with $\mathbf{0} \in \mathcal{H}$. Suppose $\exists y[B(y) \wedge \exists(S(y)|\mathcal{H})]$ is false. Since $S(y) \subseteq \exists(S(y)|\mathcal{H})$, $\exists y[B(y) \wedge S(y)]$ is false as well. Whence $\exists(B(y) \wedge S(y)|\mathcal{H}) = \mathbf{0}$, so that $\exists y \exists(B(y) \wedge S(y)|\mathcal{H})$ is false as before.

The inference is invalid for evidential $\mathcal{H}$. Once more, consider the context in figure 1, and let Jack's perceptual frame $\mathcal{H}$ be $\{M(y) \wedge F(y), M(y), F(y), M(y) \vee F(y)\}$. Then (1) is true, because:

$$\exists y \exists(B(y) \wedge S(y)|\mathcal{H}) \equiv \exists y[M(y) \wedge F(y)]$$

But

$$\exists y[B(y) \wedge \exists(S(y)|\mathcal{H})] \equiv \exists y[B(y) \wedge F(y)],$$

so (2) is false.

At this point we should highlight that the logic of vision offers predictions different from those of situation semantics. Situation semantics assumes veridicality at the lowest level: $\text{SEE}(j, R) \subseteq R$, for each relation R. Instead the filtered, possibly non-veridical properties used here, may become coarser: $R \subseteq \exists(R|\mathcal{H})$. This means, e.g., that in case of monotone determiners the inferences declared valid by the two semantics could be each other's opposite. Nevertheless, for possibly non-veridical perception the predictions of the present logic accord with our informal semantic judgments; here as well as in other cases (e.g., the connective 'and'). In case of veridical perception however the judgments of the logics are similar: both indicate that only positive formulas are veridical (here conceived of as a nonmonotonic rule).

In the paper we argue that the full logic of vision, in which conditional quantification interacts with approximations in the inverse system, can be seen as a formalisation of Husserl's philosophy of perception. The logic also suggests a semantics for some evidentials.

References

Barwise, J. 1981. Scenes and other Situations. *Journal of Philosophy* LXXVIII:369–397.

Hintikka, K. J. J. 1969. On the logic of perception. In *Models for Modalities*. Synthese Library, Vol. 23. Dordrecht: D. Reidel Publishing Company.

Kamp, H. 1984. A Scenic Tour through the Land of Naked Infinitives. Unpublished manuscript, University of Texas, Austin.

Marr, D. 1982. *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. San Fransisco: W.H. Freeman.

van Lambalgen, M., and J. van der Does. 1997. A Logic of Vision. research report LP–97–07. University of Amsterdam: ILLC.

Modal Default Reasoning (Extended Abstract)

Regine Eckardt
Universit"at Konstanz/SFB 471

The aim of my paper is, to provide a simple version of default reasoning which can be hosted in modal logics. The default logic should be capable to represent generic sentences of natural language, but also sentences where explicit reference to "normal" objects is made. I will not be concerned with nonmonotonic instanciations of generic sentences, though. I maintain that speakers' defeasible inferences about *assumedly* normal objects take place at a different level than the representation of knowledge about normal objects. I will first list a number of desirable properties which the target formalism should have, and which were reason to turn down other existing approaches. I will next present my answer to these needs, Modal Default Logic (MDL). A final discussion will conclude the paper.

1. Properties suggested by the data

Sub-Propositionality. Many default logics are centered around the propositional case. It is assumed that generic sentences refer in some way to worlds where matters are ideal with respect to the issues under consideration. A sentence like (1) will be represented according to paraphrase (1a), exemplified in (1b) by the format of Morreau[95]. (I chose this theory because it could be combined with modal logic in a straightforward fashion. The symbol > is Morreau's symbol for nonmonotonic implication.)

(1) If a baby gets breast fed, it becomes sleepy.

(1a) All babies a and events e of a's getting breast-fed are such that ... in all worlds w which are normal w.r.t. the proposition "a gets breast-fed in e" there is a state s following e where a becomes calm in s. [1]

(1b) $\forall x \forall e([BABY(x) \wedge \exists y BFEED(y,x,e)] > \exists s(e \ll s \wedge SLEEPY(x,s)))$

The underlying idea is that, even if some baby a drinks milk from the breast in e and becomes restless afterwards, there are other, ideal worlds where the drinking would have resulted in peaceful sleep. This is fine, as long as you are a generally normal baby. However, a sentence like (2) is logically incompatible with (1), as shown in steps (2a) to (2c). This is inadaequate. While baby Luzie might not be a normal baby, she may well develop her own regularities without contradicting formal logic.

(2) If baby Luzie gets breast fed, she becomes excited.

(2a) All events e of *Luzie*'s getting breast fed are such that ... in all worlds which are normal w.r.t. the proposition "*Luzie* gets breast-fed in e" there is a state s following e where *Luzie* becomes excited in s.

(2b) $\forall e([BABY(Luzie) \wedge \exists y BFEED(y, Luzie, e)] >$
$\exists s(e \ll s \wedge EXCITED(Luzie, s)))$

(2c) Instantiation of (1c) by *Luzie*:
$\forall e([BABY(Luzie) \wedge \exists y BFEED(y, Luzie, e)] > \exists s(e \ll s$
$\wedge\, SLEEPY(Luzie, s)))$

[1] In order to make things easier to read, I will ignore Morreau's parametrization: "normal according to the standards in w".

If we assume that one can't be excited and sleepy at the same time, (2b) and (2c) are incompatible. Examples like (1) and (2) lead one to conclude that generic sentences indeed state something about *normal* objects in the *actual* world, rather than transporting *all* objects into *normal* worlds.

Modality: Examples (1) and (2) have shown that the representation of defaults can't be reduced to an appropriate kind of modality. Nevertheless, it is clear that we can embed generic sentences under modal operators, and that some generic sentences in and of themselves make modal statements. The latter observation is discussed in more detail in Krifka et al. [95]. Sentences (3) to (5) exemplify the case.

(3) If fathers took care of their children, prams would have a motor.

(4) This machine slices oranges. (Stated with respect to a prototype machine which never fulfilled its purpose and never was built again.)

(5) Christs show mercy.

(6) Fly agarics have a red hat with white dots, a long white foot, ...

Sentence (3) makes counterfactual statements about worlds where generic statements different from the actual ones hold true. Sentence (4) describes what the machine should normally do if set to work. However, if it never *was* set to work, we'd make statements about the empty set unless we are allowed to peek into counterfactual worlds where it was. Sentence (5) again seems to mean more than only that normal christs show mercy. It can also express that christs are under an obligation to show mercy. Example (6), finally, is meant to stand for all those cases where actual exemplars of a certain kind never show all those properties which the ideal exemplar is claimed to have. The reader who collects mushrooms will know that (a) no mushroom ever looks like the drawing in your book (b) books with photographs are worse because the mushrooms on the photo are even less prototypical than the drawn ones. The real mushrooms all fit the description in one aspect or another, and only the fact that they all seem to be of the same kind encourages the collector to assume that they ideally should look like the picture in the book.

All these examples show that a combination of default reasoning and modal logic should be available.

Contraposition: At that stage, the unambitious user might confine himself to a version of default reasoning which, never having been discussed in connection with nonmonotonic inferences, hardly seems to deserve this name. We assume that the logical language provides a family of functors $(N_n)_{n\in\omega}$ which map each n-ary relation over the model domain M onto one of its subsets, its "normal" part. An elaboration of this idea can be found in von Fintel[t.a.], and it clearly is integratable with modal logic. Von Fintel's account, however, does not readily support the law of contraposition. We would like to be able to conclude from "A's (usually) are B" that "Non-B's usually are not-A" unless *non-B* itself is an unusual property. [2] The author proposes a restriction on the functors $(N_n)_{n\in\omega}$ which allows to integrate contraposition, yet his restriction will disallow any generic statement about non-normal objects. For example, if we have settled that humans are (usually) not albinos, the sentence "Albino humans (usually) don't like the sun" will be uninterpretable. This is undesirable. Moreover it would be nice to have an approach which relates to other theories of default reasoning.

[2] The latter qualification is exemplified by the "diabetes" pattern: "Women usually don't have diabetes" does not imply that "People who suffer from diabetes usually are male". This is due to the fact that having diabetes is a marked property.

2. Formally desirable properties

While the properties listed in the previous section are desirable for empirical reasons, I will now list three points which can be seen as a mere matter of taste. First, it would be nice to have a notion of modal default reasoning which is axiomatizable. While this requirement is almost standard in the logical community, it is often ignored by the working semantician. Second, it is of interest whether the notion of modality can be kept below the Ty2 level of explicitness. Formal semantics in the tradition of Montague is generally formulated on the basis of modal operators $\Box$ and $\Diamond$ rather than with explicit quantification over worlds, and we would like to keep up this tradition if possible. Finally, it is of interest if the underlying notion of "being normal" is definable in the logical language in use. Work on default reasoning often avoids explicit reference to "normal cases", probably due to the observation that generic sentences in natural language do not refer to normal cases either. However, once we start thinking about counterfactually normal objects it becomes clear that we have to test our intuitions on the basis of sentences where adjectives like "normal" play a role, and we certainly want to draw a link between the default cases of generic sentences and the explicitly "normal" cases (see section 4.).

3. Modal Default Logic

Definition 1: Let L be a language of modal logic with lambda abstraction over individual variables. We thus can define the notion "term of type $< e^n, t >$ " for L. Let moreover $(N_n)_{n \in \omega}$ be a family of functor symbols. For any term ϕ of type $< e^n, t >$, the expression $N_n(\phi)$ is also a term of type $< e^n, t >$. L will be called a language for MDL.

Definition 2: Let L be a language for MDL. Assume that $< M, W, I >$ is a model for the modal part of L in the usual sense. To be precise, let us assume that we work in the modal system S5. For each $n \in \omega$, interpret N_n with respect to world $w \in W$ as a functor $\mathbf{N_n}$ which maps each subset A of M^n onto a subset B of M^n. Let $\mathbf{N_n}$ have the following further properties:

(i) $\mathbf{N_n}(A) = \emptyset$ iff $A = \emptyset$

(ii) $\mathbf{N_n}(A) \subseteq A$

(iii) If $\mathbf{N_n}(A) \cap B \neq \emptyset$ then $\mathbf{N_n}(A \cap B) = \mathbf{N_n}(A) \cap B$

Condition (i) states that each property contains some elements which are normal for this property. Condition (ii) ensures that normal P's are P's at all. Condition (iii) looks less straightforward. It ensures that each property P contains elements of varying degrees of prototypicality, in a sense to be made explicit below. First note that the logic MDL can be axiomatically characterized.

Observation: The following set of axioms characterizes MDL:

(1) All instances of theorems of S5 with lambda abstraction over individuals.

(2) $\forall x_1, ..., x_n(N_n(A)(x_1, ..., x_n) \rightarrow A(x_1, ..., x_n))$

(3) $\exists x_1, ..., x_n A(x_1, ..., x_n) \rightarrow \exists x_1, ..., x_n N_n(A)(x_1, ..., x_n)$

(4) $\forall x_1, ..., x_n(A(x_1, ..., x_n) \equiv B(x_1, ..., x_n)) \rightarrow \forall x_1, ..., x_n(N_n(A)(x_1, ..., x_n) \equiv N_n(B)(x_1, ..., x_n))$

(5) $\exists x_1, ..., x_n(N_n(A)(x_1, ..., x_n) \wedge B(x_1, ..., x_n)) \rightarrow \forall x_1, ..., x_n(N_n(\lambda y_1, ..., y_n.(A \wedge B)(y_1, ..., y_n))(x_1, ..., x_n) \equiv N_n(A)(x_1, ..., x_n) \wedge B(x_1, ..., x_n))$

Evidently, (1) to (5) are sound with respect to MDL. A completeness proof can be given by extending standard completeness proofs for modal logic, for instance in Hughes/Cresswell[68], [96]. The interpretation of N_n on definable sets in the standard model will be coded in the maximal consistent set of formulae; $\mathbf{N_n}$ on undefinable sets can be chosen arbitrarily to be the identity function.

Let us now discuss the meaning of axiom scheme (5). It will ensure that each possible world w is equivalent, in terms of default implications, to a kind of model (M, R) which makes use of ranking measures $R = (R_n)_{n \in \omega}$ in order to evaluate the normality of objects in the domain. These models have been developed in Brafman[96], Weydert[97]. Intuitively, we have a ranking function R_n which maps M^n onto a linearly ordered set Ω. The higher the rank of a given element, the less normal it is. Generic sentences (viz. default implications) talk about those elements of set P which have very low rank. If each definable set A in M^n contains minimal elements, the model is called *smooth*, and default implications talk about minimal elements of P. The following definitions are taken from Weydert (Weydert[97]) and Brafman (Brafman[96]).

Let L be a logical language which is augmented by the following kind of formulae: For all formulae ϕ, ψ in L, and variables $\bar{x} = x_1, ..., x_k$, the following is also a formula in L:

$$\phi \rightarrow_{x_1,...,x_k} \psi$$

The language L is interpreted in structures (M,R) where M is an L- model in the usual sense and R is a family of ranking functions of the following shape:

(i) $R = (R_n)_{n \in \omega}$

(ii) For each $n \in \omega$, R_n is a function of D_e^n into an ordered set Ω.

(iii) For all formulae ϕ and ψ, $(M, R) \models \phi \rightarrow_{x_1,...,x_i} \psi$ iff there is an $m \in \{\bar{k} | (M, R) \models \phi(\bar{k})\}$ such that for all $n \in \{\bar{k} | (M, R) \models \phi(\bar{k})\}$ with $R_i(n) \leq R_i(m)$ we find that $(M, R) \models \psi(n)$.

Further possible restrictions to R are discussed both in Brafman and Weydert. The meaning of R will be discussed in section 4. Coming back to our case, the following equivalence result can be proved:

Theorem: Let L be a first order language, let L_{norm} be its augmentation to a language with $(N_n)_{n \in \omega}$ and L_{rank} its extension by a binary default quantifier $\rightarrow_{(x_1,...,x_n)}$ as described in Brafman, Weydert [op.cit.]. Let $*$ be an embedding of L_{rank} into L_{norm} defined by $\phi* := \phi$ for atomic formulae, $(\neg\phi)* := \neg\phi*$, $(\phi \wedge \psi)* := \phi * \wedge \psi*, ..., (\phi \rightarrow_{(x_1,...,x_n)} \psi)* := \forall x_1, ..., x_n(N_n(\phi*)(x_1, ..., x_n) \rightarrow \psi*)$.
(i) For each smooth L_{rank} model (M, R) there is an L_{norm}- model M' satisfying axioms (2) to (5) such that for all L_{rank} formulae ρ:

$$(M.R) \models \rho \text{ iff } M' \models \rho*$$

(ii) For each L_{norm} model M there is a smooth L_{rank} model (M', R) such that for all L_{rank} formulae ρ:

$$M \models \rho* \text{ iff } (M', R) \models \rho$$

Outline of proof: (i) is straightforward. In order to show (ii), we first introduce a relation $\leq$ on definable sets in M by $A \leq B$ iff $N(\lambda\bar{x}.A \vee B(\bar{x})) \subseteq A$. Axioms (2) to (5) ensure that $\leq$ is a preorder on the definable powerset over M^n, and becomes a linear order $< \Theta, \leq >$ if we proceed to equivalence classes. Using the completion $\bar{\Theta}$ of $< \Theta, \leq >$, we can define $R_n(\bar{a}) := sup\{[A] | \bar{a} \in A\}$. This ranking measure R on M will validate claim (ii).

4. The cognitive content of ranking measures

MDL has turned out to encode (smooth) ranking measures on the model domain in a way that can be integrated into modal logic. Why should that be better than some arbitrary family of normality functors, hosted in modal logic? Investigations in cognitive linguistics have shown that speakers in fact *do* have a kind of ranking amongst the elements of natural categories. Rosch, in the seventies (see Rosch[78]), and many others since have studied whether exemplars of a given category can be ordered, starting with the "good" examples and going down to the "marginal" examples. Not only could speakers make sense of tasks like "How good a piece of furniture is an X?" or "Is an A a better piece of furniture than a B?". Their rankings moreover generally coincided. Thus, speakers in fact seem to assign degrees of prototypicality to objects in a given domain. These degrees of prototypicality are not available in a numerical form, of course. The tests in prototype research used all kinds of indirect evidence for degrees of prototypicality.

The perspective I want to propose is that generic sentences are a further means to get access to prototype structure. Generic sentences of the form "A's are B" which are judged true by speakers of a given language describe the normal part of A, that is, the elements in A which have lowest rank or, equivalently, highest degree of prototypicality. Interestingly, Rosch herself stressed that "being a prototype" is not a "yes/no" question. Apart from, sometimes, being able to describe the best exemplars of a category, we can very often decide that a is a better X than b without, at the same time, claiming that a is the ideal X. This is in line with the use of ranking measures.

One might object, however, that the existence of "normal" elements in each set P does not do justice to the findings of prototype theory, where it is explicitly left open whether such a "normal" part in P exists. If we take this objection serious, we might proceed to nonsmooth ranking measures, like the ones favoured in Weydert[97]. However, it seems that an integration of nonsmooth ranking measures with modal logic requires the introduction of constants for possible worlds, that is, the use of Ty2. Moreover, it might even be necessary to be able to talk and think about the normal ones among a certain kind of objects. For instance, thinking about the rank of objects in counterfactual worlds, we will have to test our intuitions not only with sentences like (3) above, but also examples like (7).where explicit reference to normal objects of the kind "priest" is made.

(7) (John is a priest.) If John didn't have a girl friend, he would be a normal priest.

Note that the rank of John in counterfactual worlds depends on his counterfactual properties, plus the generic sentences which hold true in our and the most similar counterfactual worlds where the antecedent is true. Sentences like "John doesn't have a girl friend" do not seem to overwrite generic facts like "priests are not allowed to marry". Therefore we understand that the actual default "priests are not allowed to marry" still holds true, and determines for John as for other people whether they are normal.

This is different if the antecedent itself denies some generic fact. Consider sentence (8).

(8) If priests were allowed to marry, John would be a normal priest.

In this case, John's degree of prototypicality within the set of priests can rise even without changing any of his properties. This shows that the ranks of objects can't be read off from their properties alone. Sentences like (8) and (3) show that our ideas about "normal X's" (normal priests, normal prams, normal fathers) can counterfactually change as well as the properties of single objects. I cannot, at this place, discuss which factors decide what we *do* or *would* consider normal. The object's properties plus the current generic facts of the world taken together will (roughly) determine the ranking measure. In that respect, our interpretation of ranking measures diverges from probabilistic interpretations. [3]

It also follows from these considerations that counterfactual worlds as a whole needn't be "more normal" or "less normal" than w_0. Assume that the true generic sentences of the real world are also valid in w_{17}. While priest John, never having met his present girl friend, may have lower rank in w_{17}, Sally at the same world might have higher rank, because she counterfactually decided to spice her life as a housewife with a parachuter career [4]. Up to now, we didn't make any use of a notion of "normal worlds", apart from the idea of choosing the most plausible counterfactual worlds which underlies the current formal treatment of counterfactuals.

Our extensional perspective might be challenged by examples like (6), the fly agaric example. What if there actually isn't, wasn't and won't be any real exemplar of that species which shows all of the properties listed in your mushroom book? One way out would be, to assume that not only the objects (pairs of objects, triples, etc.) within each world are ranked, but that there moreover is a family of global ranking measures, mapping each set $W \times D_{<e",t>}$ into some ordered set Ω. The ideal fly agarics, for instance, would be found looking at the minimal pairs $< w, \tau >$ in $\lambda s \lambda x FLY\text{-}AGARIC(x, s)$. While it is quite straightforward to give *some* semantic definition of such a transworld notion of normality, a logically parsimonious version [5] which allows for a satisfactory axiomatic treatment remains to be developed.

5. References:

Brafman, R. I. (1996) : " 'Statistical' First Order Conditionals". In *Proceedings of the Fifth Conference on the Principles of Knowledge Representation and Reasoning KR 96.* Morgan Kaufmann. http://www.cs.ubc.ca/spider/brafman/home.html

von Fintel, K. (t.a.) : " Bare Plurals, Bare Conditionals, and Only". To appear in: *Journal of Semantics.*

Hughes/Cresswell(1968) *An Introduction to Modal Logic.* Routledge, London & New York.

Hughes/Cresswell(1996) *A New Introduction to Modal Logic.* Routledge, London & New York.

Kraus, S./Lehmann, D./Magidor, M. (1990) : "Nonmonotonic Reasoning, Preferential Models and Cumulative Logics". In: *Artificial Intelligence* 44 (1990), 167 - 207.

Krifka et al. (1995) : "Introduction". In: Carlson, G./Pelletier, F.: *The Generic Book.* CUP, Chicago.

Morreau, M. (1995) : "Allowed Arguments". In: *Proceedings of the 1995 IJCAI conference.* Morgan Kaufmann.

Rosch, E. (1978) : "Principles of Categorization." In: Rosch, B.LLoyd (eds) *Cognition and Categorization.* Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey.

Weydert, E. (1997) : "Rational Default Quantifier Logic". Extended Abstract, MPI for Computer Science, Saarbrücken.

[3] I don't assume that the generic facts are completely independent from other data. I only claim that it isn't a question of "most frequent = most normal".

[4] Thinking about generic sentences, I always come across the worst of my prejudices.

[5] That is, below Ty2, and without explicitly introducing binary modular ordering relations $\leq$ on $D_{<e",t>}$ which reflect the ranking measure.

Underspecification of quantifier scope

Markus Egg and Michael Kohlhase
Universität des Saarlandes, Computerlinguistik/Informatik

1 Introduction

We present an approach to a subject matter that has been discussed extensively in the literature, viz., the question of how to represent semantic structures with scope ambiguities in an underspecified way. In the following, we will focus our attention on examples like (1), which have two readings, as either quantifier may have scope over the other one:

(1) Every researcher visited a company

Many solutions have been proposed for an appropriate treatment of such examples. Some of them, e.g., UDRT (Reyle 1992), Cooper (1983), or Pereira (1990), invoke additional machinery to control the relation between the underspecified representation of sentences like (1) and its possible disambiguations. USDL (Pinkal 1996) can do without such additions to the representation formalism. However, USDL must take recourse to a metalanguage level to construct underspecified representations of structurally ambiguous sentences. In addition, the strict control over variable binding processes, which is guaranteed by other formalisms (e.g. type theory), is lost in the USDL metalanguage.

We tackle these problems by reformulating the USDL analysis of examples like (1) in λ-DRT (Kohlhase, Kuschert, and Pinkal 1996), a higher-order extension of DRT. Instead of λ-DRT itself, we use the dynamic λ-calculus $\mathcal{DLC}$ (Kohlhase and Kuschert 1997), which provides a uniform algebraic basis for λ-DRT and other compositional discourse logics. $\mathcal{DLC}$ provides the crucial type inference mechanism for strict variable control in our derivations. A dynamic base formalism allows us to express underspecified representations of scopally ambiguous sentences directly without recourse to a metalanguage.

Let us first review the original formulation. USDL is a semantic metalanguage. Its expressions denote object language expressions or operations. E.g., the constant **company′** denotes an expression in a suitable object language, say, 'λx **company′**(x)' in a language of predicate logic. '@' stands for functional application, and 'L_x' models object-level λ-abstraction over a variable x. In contrast to λx the metalevel L_x may capture free occurrences of x. For scopally ambiguous sentences S, USDL yields a set of constraints on the meaning of S, which describes the set of unambiguous readings of S. These constraints involve context variables C_n which are instantiated during the calculation of the unambiguous readings from such a constraint set. For (1), USDL deducts the set (2) of constraints over its meaning X_0:

(2) $\{X_0 = C_5(\mathbf{visit'}@y@x),\ X_0 = C_3(\mathbf{a'}@\mathbf{company'}@L_y\ C_4(\mathbf{visit'}@y@x)),$
$X_0 = C_1(\mathbf{every'}@\mathbf{researcher'}@L_x\ C_2(\mathbf{visit'}@y@x))\}$

(2) means in prose that the sentence meaning X_0 is equal to some material (C_5) applied to the skeleton sentence meaning **visit′**$@y@x$. In addition, for each of the two quantifiers, X_0 can also be described as involving the quantifier meaning applied to a λ-abstraction of a

constituent that contains the skeleton sentence meaning. This entails that each quantifier has scope over the verb that syntactically subcategorizes for it. The syntax-semantic interface alone ensures that the subscripts of the metalanguage lambda operators L_n match the variables x_n in the skeleton sentence meaning.

Applying a linear second-order unification algorithm (e.g. Niehren, Ruhrberg, and Pinkal 1997) to the constraint set (2) yields the substitution
$\{C_1 = C_4 = \lambda X.X, C_2 = \lambda X.\mathbf{a'@company'@}L_y(X), C_3 = \lambda X.\mathbf{every'@researcher'@}L_x(X)\}$

Applying this to the original set (2) yields the sentence semantics which denotes the reading of (1) with wide scope for the universal quantifier.

$$X_0 = \mathbf{every'@researcher'@}L_x\ (\mathbf{a'@company'@}L_y\ (\mathbf{visit'@}y\mathbf{@}x))$$

2 The dynamic approach

A simple rewriting of the USDL analysis to act directly on standard predicate logic fails, as solutions for contexts cannot be substituted in the same way: The free variables of the skeleton sentence must not be captured in the process of variable instantiation. E.g., short of renaming the free x_j in the equation (3), the solution $C_2 = \lambda p \exists x_j(\mathbf{company'}(x_j) \wedge p)$ (with p of type t) could not be inserted into (3). In the USDL metalevel, this 'binding' was unproblematic due to the lack of binding constraints imposed by L_x in (2). The USDL analysis of examples like (1) relies crucially on this feature of the metalanguage.

(3) $X_0 = C_1(\forall x_i(\mathbf{researcher'}(x_i) \longrightarrow C_2(\mathbf{visit'}(x_i, x_j))))$

What we need is a dynamic formalism that allows the capturing of free variables. Such a formalism would allow us to take over the USDL analyses of scope underspecification directly. It must employ a concept of dynamic binding that differs from the one employed e.g. in Dynamic Predicate Logic (DPL, Groenendijk and Stokhof 1991) in two respects:

- it assigns a certain amount of dynamicity to universal quantifiers
- its notion of dynamicity is fine-grained, to distinguish dynamicity of existential and universal quantifiers

We recast the USDL account of scope ambiguity in λ-DRT (Kohlhase, Kuschert, and Pinkal 1996), a higher-order extension of DRT. As in USDL, we render the meaning of a sentence by a constraint set over this meaning, which can describe more than one unambiguous reading. Deriving unambiguous readings from such constraint sets, in particular, the problematic case of quantifier insertion (as in (3)), is easy in $\mathcal{DLC}$.

Underspecification enters by giving the meaning of constituents (especially, of sentences) in terms of equations in λ-DRT. This formalism combines the Montagovian type theoretic framework (Montague 1974) with dynamic approaches, such as DRT: it uses β-reduction to compute a first-order DRT representation of sentences from higher-order lexical items.

The capturing of free variables, *the* thing impossible in pure λ-calculus, is the driving force of the establishment of anaphoric binding in λ-DRT. We will use this very possibility of capturing variables in a controlled way to formalize quantifier underspecification.

Next, we will sketch $\mathcal{DLC}$ (the implementation of λ-DRT in this paper), and give an example of using higher-order unification in $\mathcal{DLC}$ to represent quantifier underspecification.

3 Dynamic λ-Calculus

The central idea of $\mathcal{DLC}$ is extending the type system to incorporate information on variables. Types of $\mathcal{DLC}$ expressions have a 'mode' part that lists their free variables (that can be captured) and their binders (that can dynamically capture free variables). Modes annotate variables with '-', and binders, with '+'. E.g., the type $X^-, U^+\#t$ describes propositions with a free variable X that dynamically bind a variable (and introduce a discourse referent) U. Since $\mathcal{DLC}$ is a λ-calculus, the set of types is closed under function types.

$\mathcal{DLC}$-formulae are λ-calculus formulae together with dynamic abstractions of the form $\delta U.\mathbf{A}$. $\mathcal{DLC}$-well-typedness is verified (from type assumptions in a signature Σ and a variable context $\mathcal{A}$) using a variant of the classical λ-calculus inference system: $\mathbf{A}$ is a well-formed $\mathcal{DLC}$ formula of type α, iff the judgement $\mathcal{A} \vdash \mathbf{A}\colon\alpha$ is provable in the λ-calculus inference system with an added rule for δ-abstractions and where the λ-abstraction rule has been modified to manipulate the mode information in the types as indicated below.

$$\frac{\mathcal{A}, [U\colon U^-\#\overline{\overline{\beta}}] \vdash \mathbf{A}\colon\alpha}{\mathcal{A}, [U\colon U^-\#\overline{\overline{\beta}}] \vdash \delta U_\beta.\mathbf{A}\colon U^+\#\alpha} \qquad \frac{\mathcal{A}, [X\colon\Gamma^-\#\overline{\overline{\beta}}] \vdash \mathbf{A}\colon\alpha \quad X \notin \mathbf{Dom}(\Gamma)}{\mathcal{A} \vdash (\lambda X_\beta.\mathbf{A})\colon(\Gamma^-\#\overline{\overline{\beta}}) \to \alpha}$$

$\overline{\overline{\alpha}} = \alpha$, and $\overline{\overline{\alpha \to \beta}} = \Gamma\#\alpha \to \Delta\#\beta$ for new modes Γ and Δ. In the merging of modes, positively signed variables overwrite negatively signed ones of the same type and name. This overwriting is important for the last rule for *dynamic abstraction*, where U^- may have been present in Γ, indicating the presence of a free variable U in $\mathbf{A}$. It is this overwriting effect that models the variable capturing at function application on the syntactic side.

The types of λ-abstractions explicitly pass on mode information from arguments of applications. Thus, the rule discharges the type assumption about the variable X from the variable context, since it is no longer free in the abstraction. Read backwards, this move augments the variable context with type information for X. The set of possible types of X_β in $\lambda X_\beta.\mathbf{A}$ is $\Gamma^-\#\overline{\overline{\beta}}$. The Γ^- part stands for the (as yet unknown) set of free variables of the argument. If the argument is itself functional, $\overline{\overline{\beta}} \neq \beta$, which reflects the fact that we do not know yet how the argument affects the free variables of its own argument within $\mathbf{A}$. (For details, see Kohlhase and Kuschert 1997.) The rule also enforces a kind of occurs-check for X in Γ^-. Finally, we assume the type identity $\Gamma\#(\Delta\#\alpha) = \Delta, \Gamma\#\alpha$ for all Γ, Δ, α.

Given this, we attain λ-DRT by fixing the set of base types to $\mathcal{BT} = \{e, t\}$ (individuals and truth values) and defining a set of connectives as conjunction, disjunction, negation and implication. In standard DRT, the binding properties of discourse referents in the context must be defined in an accessibility relation. With the extended type system, we can now express this relation directly in the syntax. E.g., we define a collection of dynamic implication operators of type $\Rightarrow_{\Gamma\Delta}\colon(\Gamma\#t) \to (\Delta\#t) \to ((\Gamma^-, (\Delta^- \setminus \Gamma^+))\#t)$. where Γ^- is the set of negatively signed variables in the mode Γ. The mode of the type that results from applying the two arguments to the operator, $\Gamma^-, (\Delta^-/\Gamma^+)$, captures the accessibility relation between the two arguments: apart from the free variables of the first argument of the quantifier, only those free variables of the second argument are available to the outside which are not bound by the discourse referents of the first argument.

4 Example

We will now apply our analysis to sentence (1). Just like USDL, it generates the constraints

$$X_0 = C_1(\mathsf{er}(C_3(\mathsf{vis}UV))) = C_2(\mathsf{ac}(C_4(\mathsf{vis}UV)))$$

where variables C_i have types $\overline{\overline{t \to t}} = (\Gamma_i \# t) \to (\Xi_i \# t)$; 'er' and 'ac' abbreviate the semantics of *every researcher* and *a company*. We assume the following lexicon:[1]

word	formula	type
visited	vis	$\Gamma^- \# e \to \Delta^- \# e \to \Gamma^- \cup \Delta^- \# t$
sleeps	sleeps	$\Gamma^- \# e \to \Gamma^- \# t$
researcher	res	$\Gamma^- \# e \to \Gamma^- \# t$
company	comp	$\Gamma^- \# e \to \Gamma^- \# t$
every	$\lambda R_{e\to t}.\lambda Q_t.(\delta U_e.RU) \underline{\Rightarrow} Q$	$(\Gamma \# e \to t) \to (\Delta, U^- \# t) \to (\Gamma^- \cup (\Delta^- \setminus \Gamma^+)) \# t)$
a	$\lambda R_{e\to t}.\lambda Q_t.\delta V_e.RV \otimes Q$	$(\Gamma \# e \to t) \to (\Delta, V^- \# t) \to (\Gamma \cup \Delta, V^+) \# t)$

By the added expressivity of $\mathcal{DLC}$ we can express the behaviour of binders and variables in the types of $\mathcal{DLC}$ expressions. As functional application and instantiation of mode variables must be well-typed, the linear higher-order unification and the simplification of type constraints induced by type inference mutually constrain each other, giving us a powerful mechanism for propagating information about variables and quantifiers binding them.

In addition to the constraints taken over from USDL, we can use $\mathcal{DLC}$ types to encode the general observation that, at text level, there may be no free variables except those introduced by deictic pronouns. (Single sentences qualify as a text, too, if they occur in isolation.) This entails that if the type of the sentence (1) is $\Theta \# t$ then $\Theta^- = \emptyset$, and, in particular, the variables U and V are no longer free at the sentence level.

Let us now calculate the type constaints Γ_i and Ξ_i imposed by the equational constraints: $\mathsf{vis}UV$ is of type $U^-, V^- \# t$, hence, $\Gamma_3 = \Gamma_4 = U^-, V^-$. The domain type of er is Δ, U^- and that of ac is Δ', V^-, so $\Xi_3 = \Delta, U^-$ and $\Xi_4 = \Delta', V^-$. Analogously we obtain values for the type of C_1 and C_2, which entails the following type judgements.

$C_1 \colon (\Delta^- \# t) \to (\Theta \# t)$	$C_2 \colon (\Delta', V^+ \# t) \to (\Theta \# t)$
$C_3 \colon (U^-, V^- \# t) \to (\Delta, U^- \# t)$	$C_4 \colon (U^-, V^- \# t) \to (\Delta', V^- \# t)$

Now we start linear unification, calculating and simplifying the type constraints after each step. First, we project the variable C_1, i.e., we guess that $C_1 = \lambda Z_t.Z$. This yields the wide scope reading of *every researcher* for (1). Linear imitation for C_1 is also possible and yields the narrow scope reading. Since $\lambda Z_t.Z$ has type $(\Psi \# t) \to (\Psi \# t)$, we have

$\Delta^- = \Theta$	$C_1 \colon (\Theta \# t) \to (\Theta \# t)$

[1] Since we omit modification here, we assume simplified types of nouns and verbs. We enforce non-degenerate binding for quantifiers that dynamically bind some variable U, by adding the mode U^- to the type specification of the mode Δ in the above representations of quantifiers. This expresses that they require a free variable U in their second argument.

Thus even at this early stage of the computation, we can see that

- Θ is empty, because by $\Delta^- = \Theta$ it contains no positive variables and by the status of (1) as a text it contains no negative variables. I.e., X_0 has neither free variables nor binding potential. This was to be expected, as the reading of (1) we are looking at is a text in which the universal quantifier *every researcher* has widest scope.
- the value of C_3 binds V: V^- is in the argument but not the target type mode of C_3.

In the next unification step, we imitate C_2, since the projection would lead to immediate failure, i.e. we bind C_2 to $\lambda Z_t.\mathsf{er}(C_5 Z)$, where C_5 is a new variable of characteristic type (i.e., the type without mode) $t \to t$. Type inference reveals that the type of C_5 is

$$\boxed{C_5 \colon (\Delta', V^+\#t) \to (\Delta, U^-\#t)}$$

After decomposition the problem has the form $C_3(\mathsf{vis}UV) = C_5(\mathsf{ac}(C_4(\mathsf{vis}UV)))$. We continue by projecting ($C_5 = \lambda Z_t.Z$) and get the type constraint $\Delta', V^+\#t = (\Delta, U^-\#t)$ (argument and target types of $\lambda Z.Z$ must be identical) or equivalently for a new mode Φ.

$$\boxed{\Delta' = \Phi, U^- \qquad \Delta = \Phi, V^+}$$

Now we imitate C_3 by binding it to $\lambda Z_t.\mathsf{ac}(C_6 Z)$. C_6 is a new variable of type

$$\boxed{C_6 \colon U^- V^- \#t \to (\Phi, U^-, V^-\#t)}$$

Decomposition yields $C_6(\mathsf{vis}UV) = C_4(\mathsf{vis}UV)$. If we guess that $C_4 = C_6 = \lambda Z_t.Z$, the completion of the linear unification is trivial. Type inference gives us the constraints

$$\boxed{\Phi = \emptyset \qquad \Delta = V^+ \qquad \Delta' = U^-}$$

Collecting all constraints makes all the dynamic potentials explicit:

variable	value	type
C_1	$\lambda Z_t.Z$	$t \to t$
C_2	er	$(U^-, V^+\#t) \to t$
C_3	ac	$(U^-, V^-\#t) \to (U^-, V^+\#t)$
C_4	$\lambda Z_t.Z$	$(U^-, V^-\#t) \to (U^-, V^-\#t)$
X_0	(er(ac(vis U V)))	t

5 Conclusion and further work

To sum up, in this paper we have presented an approach to the underspecified representation of scopally ambiguous sentences that accounts for them directly in terms of a dynamic lambda calculus, without having to rely on additional machinery. Deriving fully specified readings from underspecified representations involves only simple substitutions of typed context variables. The binding potential of expressions is highlighted throughout, in the derivation and in the resolution of the constraints on sentence meanings.

So far, we used the strict record on binders and variables merely to make the treatment of binders and variables explicit. But we expect the proposed approach to prove useful in restricting potential ambiguities within texts. Consider e.g. forcing wide scope of the existential quantifier in an example like (4) by picking up the referent of the quantifier anaphorically in the next sentence. This can easily be described in our formalism:

(4) Every researcher visited a company. It belonged to a tycoon.

Omitting deictic use of pronouns, we request (complete) texts to contain no free variables, that is to say, all free variables introduced in the text must be bound off within it as well. Hence, if the type of the second sentence in (4) is $\Delta^+, U^- \# t$ (the free variable U is introduced by the pronoun *it*), there has to be a preceding sentence in the text whose mode comprises a binder for U, i.e., is of type $\Gamma, U^+ \# t$, for any Γ. In (4), this restricts the ambiguity of the first sentence in the desired way: It must provide a binder for the variable as introduced by the pronoun, which excludes the reading in which the indefinite quantifier has narrow scope w.r.t. the universal quantifier. Scoping a universal quantifier over an existential would have 'shadowed off' the binding potential of the existential quantifier.

The proposed approach will also be of use in the domain of nested quantifiers: It provides strict control over variables and their binders, which are needed to rule out overgeneration (as noted by e.g. Nerbonne 1992). Our approach provides this control and therefore blocks overgeneration even in examples like (5):

(5) Everyone with a picture of himself arrived

The unwanted solution with wide scope of the existential quantifier is ruled out: Its mode would still contain a free variable, which clashes with the presupposed type for texts.

References

Cooper, R. (1983). *Quantification and syntactic theory.* Dordrecht: Reidel.

Groenendijk, J. and M. Stokhof (1991). Dynamic predicate logic. *Linguistics & Philosophy 14*, 39–100.

Kohlhase, M. and S. Kuschert (1997). *Dynamic λ-Calculus.* CLAUS-Report 92, Uni. d. Saarl.

Kohlhase, M., S. Kuschert, and M. Pinkal (1996). A type-theoretic semantics for λ-DRT. In P. Dekker and M. Stokhof (eds), *Proc. 10th Amsterdam Colloquium*, 479–498. ILLC.

Montague, R. (1974). The proper treatment of quantification in ordinary English. In R. Montague (ed.), *Formal Philosophy. Selected Papers.* New Haven: Yale University Press.

Nerbonne, J. (1992). A feature-based syntax/semantics interface. DFKI Report RR-92-42.

Niehren, J., P. Ruhrberg, and M. Pinkal (1997). On equality up-to constraints over finite trees, context unification and one-step rewriting. In *Proceedings of CADE'97.*

Pereira, F. (1990). Categorial semantics and scoping. *Computational Linguistics 16*, 1–10.

Pinkal, M. (1996). Radical underspecification. In P. Dekker and M. Stokhof (eds), *Proceedings of the 10th Amsterdam Colloquium*, 587–606. ILLC, Amsterdam.

Reyle, U. (1992). Dealing with ambiguities by underspecification: a first order calculus for unscoped representations. In *Proceedings of the Eighth Amsterdam Colloquium.*

The Logic of Ambiguity

Jan van Eijck (CWI) and Jan Jaspars (UvA)

Abstract

The paper proposes a logic of ambiguity that takes a large number of natural intuitions about ambiguous entailment into account, by employing evaluation in models with a disambiguation function. Also, the logic satisfies a natural requirement of monotonicity: ambiguous entailments are preserved under further disambiguation. It is sketched how this entailment notion can be axiomatized using Gentzen sequents.

Introduction

Processing ambiguous and underspecified NL utterances is an active and growing research area in NLP. Three subtasks should be distinguished in this field:

1. producing appropriate representations for ambiguous or underspecified utterances,
2. specifying procedures for resolution of ambiguity and underspecification of such representations,
3. developing the logic of ambiguous and underspecified languages in its own right.

The third task in this list is motivated by the fact of life that human beings are able to draw conclusions from ambiguous information.

Once these tasks are clearly separated, it becomes evident that (3) is more or less independent of (1) and (2), and it is rather surprising, therefore, that the topic of reasoning with ambiguous expressions has until now not received the attention it deserves. Calculi for handling ambiguity that have been proposed almost always concern tasks (1) and (2), and almost never address task (3), the prevailing attitude in the literature being that knowing how to arrive at the full disambiguations of an ambiguous expression, and knowing what these full disambiguations mean constitutes all there is to the meaning of ambiguity (see [?]).

Another reason for neglecting task (3) is that the representation issue for ambiguous languages often comes up in the context of natural language systems with very expressive representation languages. Specifying a semantics for the non-ambiguous versions of such formalisms is already far from trivial, so it is not surprising that spelling out the meanings of their extensions with ambiguous expressions presents a too formidable task.

We therefore propose to tackle task (3) by starting from scratch, by grafting a construction for representing ambiguities on well understood logical languages such as ordinary propositional and predicate logic, and investigating the resulting logics. Once the mechanism is understood in these simple contexts, the analysis of ambiguous extensions of more expressive languages becomes feasible.

Desiderata for Ambiguous Consequence

Point of departure for arriving at a decent notion of entailment for ambiguous expressions should be a list of desiderata provided by semantic intuition. Such semantic intuitions exist, for in real life situations human beings do in fact reason with ambiguous utterances. Intuitively, from *Bill went to the bank* it follows that Bill went somewhere, even in situations where *bank* is ambiguous.

Suppose we use $?(\phi,\psi)$ for a proposition that is ambiguous between ϕ and ψ. Then the following are reasonable desiderata for reasoning with $?(\phi,\psi)$ (we use $\models_a$ for ambiguous consequence):

$$
\begin{aligned}
?(\phi,\psi) &\models_a \phi\vee\psi\\
\phi\wedge\psi &\models_a ?(\phi,\psi)\\
\neg?(\phi,\psi) &\models_a \neg\phi\vee\neg\psi\\
\neg\phi\wedge\neg\psi &\models_a \neg?(\phi,\psi)\\
?(\phi,\psi) &\not\models_a \phi\wedge\psi\\
\phi\vee\psi &\not\models_a ?(\phi,\psi)\\
\neg?(\phi,\psi) &\not\models_a \neg\phi\wedge\neg\psi\\
\neg\phi\vee\neg\psi &\not\models_a \neg?(\phi,\psi).
\end{aligned}
$$

Furthermore, $?(\phi,\psi)\wedge\neg?(\phi,\psi)$ need not be a contradiction: *A ball is a toy and a ball is not a toy* is not contradictory, provided we give the two occurrences of *ball* a different sense. Similarly, $?(\phi,\psi)\vee\neg?(\phi,\psi)$ need not be a logical truth.

These intuitions may serve to show that the naive attempt to kill off the subject before it gets underway, by treating ambiguity as object level disjunction, will never work. If $?(\phi,\psi)$ is made equivalent to $\phi\vee\psi$, then $\neg?(\phi,\psi)$ will have to be equivalent to $\neg\phi\wedge\neg\psi$ (unless one proposes to change the meaning of negation, of course), and this gives the wrong interplay between ambiguity and negation.

So there is indeed meat to the subject. Ambiguous representations of the meanings of natural language sentences have been proposed in the literature to represent various kinds of unresolved underspecified information. A well-known formalism for this is quasi logical form (QLF) [?], a formal language which leaves several kinds of ambiguity unresolved, in order to separate the processing tasks of grammatical analysis and contextual specification of implicit information.

A formal semantics for QLF has been proposed in Alshawi and Crouch [?], in terms of so-called *monotonic interpretation*. The essence of the proposal is simply this. Basically, an ambiguous expression, i.e., a QLF with multiple LF resolutions, is true if *all* its resolutions are true, and it is false if *all* of its disambiguations are false. This choice complies with the monotonicity requirement on resolution of ambiguity, which says that if an expression ϵ_1 is further resolved to ϵ_2 then the interpretation of ϵ_2 should be at least be as specific as the interpretation of ϵ_1. In other words, in models where ϵ_1 is true (false), ϵ_2 should be true (false) as well.

This way of evaluating ambiguous expressions induces partiality. If the truth-values of the set of unambiguous readings are not all the same, then the original expression is left undefined. Furthermore, if a QLF has no readings, then this treatment induces overdefinedness.

Here we will study the logical foundation of such a truth-functional treatment, for clarity of exposition confining ourselves to a propositional setting. Although the QLF references do not bother to give a further analysis of logical validity and ambiguous consequence, we think that such an analysis is needed.

A first reasonable approximation to the relation $\models_a$ of ambiguous consequence is to consider $?(\phi,\psi)$ true if both ϕ and ψ are true, false if both ϕ and ψ are false, and undetermined otherwise, and to combine this semantics with the well-known double-barrelled consequence relation from partial logic. This accounts for all of the above intuitions, and yields a logic that satisfies monotonicity under further disambiguation. A calculus for this consequence relation was presented and analysed in [?].

One unfortunate feature of the double-barrelled consequence relation $\models^2$ is that it yields $?(\phi,\neg\phi)\ \models^2\ ?(\psi,\neg\psi)$, for arbitrary ϕ, ψ. The reason is that $?(\phi,\neg\phi)$ will always have truth value undetermined. Due to the ruling that an ambiguous expression is true iff *all* of its readings are true, all ambiguities between mutually exclusive alternatives become equivalent.

A second problem is that $?(\phi, \psi) \wedge \neg ?(\phi, \psi)$ is indeed not a contradiction, for in models where ϕ and ψ have different truth values (or are both undetermined), the formula $?(\phi, \psi) \wedge \neg ?(\phi, \psi)$ is undetermined. However, the formula has the desired property for the wrong reasons, so to speak, for the intuitive non-contractoriness of *a ball is a toy and a ball is not a toy* is caused by the two readings of the ambiguous expression that it contains, while both occurrences of $?(\phi, \psi)$ in $?(\phi, \psi) \wedge \neg ?(\phi, \psi)$ get the same interpretation.

A problem of a different nature is the following. Note that we have:

$$?(\phi, \psi), \neg \phi \not\models_a \psi.$$

This fact does not agree with our intuition about ambiguous consequence, for if someone says something that is ambiguous between ϕ and ψ, and next asserts that ϕ is false, then we naturally conclude that the speaker must have meant ψ with his first utterance. The example shows that features of the premise set may play a role in disambiguation.

Our proposal s to enrich the model theory of ambiguous languages with partial disambiguation functions. A PD is a map from an ambiguous language to the power set of its unambiguous core that resolves some (or all) of its ambiguities. Assuming that ϕ, ψ are unambiguous, a PD may map $?(\phi, \psi)$ to $\{\phi, \psi\}$, to $\{\phi\}$ or to $\{\psi\}$. Ambiguous formulas are now evaluated with respect to model-PD pairs: $?(\phi, \psi)$ is true in M, given PD a, iff all disambiguations that a gives for $?(\phi, \psi)$ are true, false in M given a iff all disambiguations that a gives for $?(\phi, \psi)$ are false, and undetermined otherwise, Ambiguous consequence can then be defined in the standard fashion as: every model-PD pair that makes the premisses true makes the conclusion true. This turns out to account for all of the above intuitions.

A Gentzen sequent axiomatisation of the propositional version of this logic and a completeness proof can be given, using a format with sets of finite sets of formulas (encoding a finite number of readings for an ambiguous proposition). The Gentzen derivation that accounts for the first intuition above looks like this:

$$\dfrac{\dfrac{\dfrac{\{\phi\} \Rightarrow \{\phi\} \quad \{\psi\} \Rightarrow \{\psi\}}{\{\phi, \psi\} \Rightarrow \{\phi\}, \{\psi\}} \text{ ambig left}}{\{?(\phi, \psi)\} \Rightarrow \{\phi\}, \{\psi\}} \text{ ? left}}{\{?(\phi, \psi)\} \Rightarrow \{\phi \vee \psi\}} \vee \text{ right}$$

Disambiguation Semantics

The language $\mathcal{L}$ is the language of propositional logic with a an ambiguation operator $?(\phi, \psi)$. We use $\mathcal{L}_0$ for standard language of propositional logic. Roman lower case letters $p, q, r, p', \ldots$ will be used as propositional variables, Greek lower case letters $\phi, \psi, \phi_1, \phi', \ldots$ denote $\mathcal{L}$-formulae. Roman upper case letters $A, B, \ldots$ refer to finite $\mathcal{L}$-formula sets (ffs's), while Greek upper case letters $\Gamma, \Delta, \ldots$ refer to sets of finite $\mathcal{L}$-formula sets (sffs's). We will use sets, and also sets of sets, of formulae as arguments of connectives. These expressions should be read distributively: $\neg A := \{\neg\phi \mid \phi \in A\}$, $A \wedge B := \{\phi \wedge \psi \mid \phi \in A, \psi \in B\}$, $\neg\Gamma := \{\neg A \mid A \in \Gamma\}$, and so on.

Here is a semantics for disambiguation dependent logics, where the evaluation of ambiguous expressions is related to a state of information, or context, where it may be the case that certain ambiguous expressions have already been partially disambiguated. Such a state is called a *partial disambiguation*.

A *partial disambiguation* is a function $\mathsf{a} : \mathcal{P}_f\mathcal{L} \longrightarrow \mathcal{P}_f\mathcal{L}_0$ (from finite subsets of the full language to finite subsets of the unambiguous sublanguage) satisfying the following requirements:

$$\begin{aligned}
\mathsf{a}(\{p\}) &= \{p\} \\
\mathsf{a}(\{\neg\phi\}) &= \neg\,\mathsf{a}(\phi) \\
\mathsf{a}(\{\phi \wedge \psi\}) &= \mathsf{a}(\phi) \wedge \mathsf{a}(\psi) \\
\mathsf{a}(\{?(\phi,\psi)\}) &= \mathsf{a}(\{?(\phi,\psi)\}) \subseteq \mathsf{a}(\phi) \cup \mathsf{a}(\psi) \\
\mathsf{a}(A) &= \emptyset \text{ iff } A = \emptyset \\
\mathsf{a}(A \cup \{?(\phi,\psi)\}) &= \mathsf{a}(A \cup \{\phi,\psi\}).
\end{aligned}$$

Intuitively, a partial disambiguation of a finite set of $\mathcal{L}_0$ formulas is as least as informative as the set itself. Note that partial disambiguations of singleton sets always are singletons. A partial disambiguation of A fully disambiguates A if it is a singleton.

We use Pd for the set of partial disambiguations. A disambiguation valuation D is a pair $\langle V, \mathsf{a}\rangle$ with $V \in \mathsf{V}$ and $\mathsf{a} \in \mathsf{Pd}$. The collection of disambiguation valuations is denoted by D. A formula $\phi \in \mathcal{L}$ is true in a model $D = \langle V, \mathsf{a}\rangle$ iff $V \models \mathsf{a}(\phi)$, false in D if $V \dashv \mathsf{a}(\phi)$. We write $D \models \phi$ and $D \dashv \phi$, respectively.

In this disambiguation dependent setting we no longer need the double barreled entailment relation to get the desired disjunctive effect:

$$\Gamma \models_{\mathsf{D}} \phi_1, \ldots, \phi_n \text{ and } \neg\Gamma \models_{\mathsf{D}} \neg\phi_1, \ldots, \neg\phi_n.$$

In particular,

$$\begin{array}{llllll}
?(\phi_1,\phi_2) & \models_{\mathsf{D}} & \phi_1 \vee \phi_2 & \text{and} & \neg\,?(\phi_1,\phi_2) \models_{\mathsf{D}} & \neg\phi_1 \vee \neg\phi_2 \quad \text{, while} \\
?(\phi_1,\phi_2) & \not\models_{\mathsf{D}} & \phi_1 \wedge \phi_2 & \text{and} & \neg\,?(\phi_1,\phi_2) \not\models_{\mathsf{D}} & \neg\phi_1 \wedge \neg\phi_2.
\end{array}$$

This makes it possible to get rid of all the disadvantages of the double barreled approach to ambiguous consequence.

Sequent Axiomatisations

In a sequent style formalization of the logic of ambiguity, it is natural to use set of finite formula sets (sffs'). The idea behind this is that the finite formula sets represent sets of (possibly partial) resolutions of some ambiguous expression. In a standard Gentzen system, the left-hand side of a sequent is read conjunctively, the righthand side disjunctively. Our sequents over sets of finite formula sets make it possible to treat ambiguity Gentzen style by reading each finite formula set as a '?'. In other words, the reader should have a $? \wedge \ldots \wedge ? \vdash ? \vee \ldots \vee ?$ interpretation scheme for sequents in mind.

An sffs-sequent looks like an ordinary sequent, except for the fact that its main ingredients are sffs's. We will limit the use of brackets in the presentation of sffs-sequent systems, as follows. We do not use outer brackets for sffs's. Empty sffs's are just written as blanks, so if s is a set of sequent rules, $\vdash_{\mathsf{s}} \Delta$ means that Δ is s-derivable from the empty sffs , and $\emptyset \vdash_{\mathsf{s}} \Delta$ means that Δ is derivable from the singleton sffs containing only the empty set. Furthermore, we use Γ, Δ for $\Gamma \cup \Delta$, we use Γ, A for $\Gamma \cup \{A\}$, and $A \ \ \phi$ for $A \cup \{\phi\}$.

Sequent rules to deal with sets of readings look like this (the precise format depends on further constraints we can impose on the disambiguation functions):

$$\frac{\Gamma, A \vdash \Delta \quad \Gamma', B \vdash \Delta'}{\Gamma, \Gamma', A \cup B \vdash \Delta, \Delta'} \text{ ambig-left} \qquad \frac{\Gamma \vdash A, \Delta \quad \Gamma' \vdash A, \Delta'}{\Gamma, \Gamma' \vdash A \cup B, \Delta, \Delta'} \text{ ambig-right}$$

Sequent rules for dealing with the ambiguity operators can now simply take advantage of the extra layer of ambiguous sets:

$$\frac{\Gamma, A \cdot \phi \cdot \psi \vdash \Delta}{\Gamma, A \cdot ?(\phi, \psi) \vdash \Delta} \ ?\text{-left} \qquad \frac{\Gamma \vdash \phi \cdot \psi \cdot A, \Delta}{\Gamma \vdash ?(\phi, \psi) \cdot A, \Delta} \ ?\text{-right}$$

The reader will have to take it on trust that we have a sound and complete proof system for this logic (or rather, for various variants of it resulting from a variety of conditions on behaviour of the partial disambiguations), and that the language can be extended in a natural way with a well behaved implication operator (well-behaved in the sense that it satisfies the natural left and right sequent rules), for which we also have a sound and complete axiomatisation. See [?] for some further details. The approach has natural extensions to the expressive formalisms used in natural language semantics.

References

[1] H. Alshawi, editor. *The Core Language Engine.* MIT Press, Cambridge Mass, Cambridge, Mass., and London, England, 1992.

[2] H. Alshawi and R. Crouch. Monotonic semantic interpretation. In *Proceedings 30th Annual Meeting of the Association for Computational Linguistics*, pages 32–38, 1992.

[3] D. van Deemter and S. Peters, editors. *Semantic Ambiguity and Underspecification.* CSLI Lecture Notes, Stanford, 1996.

[4] J. van Eijck and J. Jaspars. Ambiguity and reasoning. Technical Report CS-R9616, CWI, Amsterdam, 1996.

[5] J. Jaspars. Minute Logics for Reasoning with Ambiguous Expressions. Draft Paper, University of Amsterdam, 1997.

A modal logic for non-deterministic disambiguation

Tim Fernando

Stuttgart and CMU

Abstract. Disambiguation is investigated through Kripke frames with states given by pairs $(\overline{e}, \overline{\varphi})$ of sequences $\overline{e} = e_1 \cdots e_n$ and $\overline{\varphi} = \varphi_1 \cdots \varphi_n$ of (possibly ambiguous) expressions e_i and (unambiguous) formulas φ_i, where φ_i is (in a precise sense) a disambiguation of e_i, relative to a context in which $e_1 \cdots e_{i-1}$ occurs to the left (or past) of e_i, and $e_{i+1} \cdots e_n$ occurs to the right (or future) of e_i. The accessibility relations of the frame are of two kinds: on input e, the state $(\overline{e}, \overline{\varphi})$ may move to a state of the form $(\overline{e}e, \overline{\varphi}\varphi)$; without any input, $(\overline{e}, \overline{\varphi})$ may turn to a state $(\overline{e}, \overline{\psi})$, re-interpreting (as it were) the past input data $\overline{e}$. A multi-modal language is defined that captures bisimulation equivalance between models based on such frames. Decidability and the finite model property are, under suitable conditions, established.

1 Introduction

A familiar fact about interpreting an arbitrary English sentence e is its context-dependence: in isolation from the context in which it occurs, e can mean any number of things; that range of meanings can be narrowed down, given some information about the context in which e is uttered. For example, by itself, the sentence

`A friend of every student in her class loves squash`

is ambiguous in ways that it (presumably) is not, within the discourse

`Doris couldn't believe it. A friend of every student in her class loves squash. He is very popular and eats it raw.`

Against a background of such examples, the present work aims to examine abstractly the effects of discourse on disambiguation. A concrete picture useful for orientation is that of a system interpreting English sentences as (well-formed) formulas of some formal language; inasmuch as that formal language has a well-defined semantics, interpreting an English sentence by a formula in that language amounts to disambiguation.

The idea then is to study discourse interpretation through a set State of pairs $(\overline{e}, \overline{\varphi})$ of sequences $\overline{e} = e_1 \cdots e_n$ and $\overline{\varphi} = \varphi_1 \cdots \varphi_n$ of English sentences e_i and formulas φ_i (respectively) such that

(∗) φ_i is (in a precise sense) a disambiguation of e_i, relative to a context in which $e_1 \cdots e_{i-1}$ occurs to the left (or past) of e_i, and $e_{i+1} \cdots e_n$ occurs to the right (or future) of e_i.

In particular, the pair $(\emptyset, \emptyset)$ of empty sequences is an element of State, reflecting the state of an interpretation system that has not been fed any input. ¿From this initial state, the system can, given an input e, make a transition to (e, φ), provided $(e, \varphi) \in$ State. More generally, from a state $(\overline{e}, \overline{\varphi})$, the system can, given input e, move to $(\overline{e}e, \overline{\varphi}\varphi)$, as long as $(\overline{e}e, \overline{\varphi}\varphi) \in$ State. Or without any input, the state $(\overline{e}, \overline{\varphi})$ might change to $(\overline{e}, \overline{\psi})$, provided $(\overline{e}, \overline{\psi}) \in$ State — entertaining, as it were, a re-interpretation $\overline{\psi}$ of the first component $\overline{e}$ of the pair $(\overline{e}, \overline{\varphi})$. Notice that a record of the past inputs is always kept, whether or not past outputs are re-considered.

Now, our present purposes can be served by proceeding abstractly, and taking for granted a set E of "expressions", related to a set Φ of formulas by a function $\delta : E \to Power(\Phi)$ such that intuitively for every $e \in E$,

$$\delta(e) \quad = \quad \{\varphi \in \Phi \ : \ e \text{ can be "disambiguated" as } \varphi\} \ .$$

$\delta(e)$ says only what formulas in Φ e *can* be disambiguated to, and nothing about the contexts under which e is disambiguated to a particular $\varphi \in \delta(e)$. To introduce an element of context, let us suppose also that we are given a function $[\cdot,\cdot,\cdot] : (E \times E \times E) \to E$, supporting the intuition that for all expressions $l, e, r \in E$,

$$[l, e, r] \quad = \quad \text{an expression disambiguating } e \text{, assuming } l \text{ occurs to the left of } e \text{, and } r \text{ to the right of } e \ ,$$

assuming (for the sake of simplicity) that $\Phi \subset E$. (As with δ, different choices of $[\cdot,\cdot,\cdot]$ are possible, the point of the present investigations, initiated in Fernando 1995, being to study the consequences of such choices.) The disambiguation of e by $[l, e, r]$ is, unlike $\delta(e)$, not only

(a) sensitive to the context l, r

but also

(b) deterministic, insofar as $[l, e, r]$ is a specific expression, rather than a set of unambiguous formulas

and

(c) partial, in the sense that $[l, e, r]$ may (assuming $e \in E - \Phi$) well be an element of $E - \Phi$.

In particular, if the context l, r provides no information to disambiguate an ambiguous expression $e \in E - \Phi$, it is natural to expect $[l, e, r] = e$. In this sense, $[l, e, r]$ allows for *lazy* disambiguation, the strategy being to *wait* for an extension l', r' of the context l, r that would disambiguate e. But what if no such extension exists? Then it would make sense to *guess* some value from $\delta(e)$. Having introduced non-determinism, the present paper goes whole hog, by considering a *total* disambiguation strategy in which an unambiguous formula can be extracted from $[l, e, r]$ by guessing an extension r' of r for which $[l, e, r'] \in \Phi$. To keep things from getting out of hand, these guesses are recorded in states, structured by a labeled transition system, with a modal logic.

2 Transitions disambiguating expressions

More formally, let us assume that the set E of expressions is closed under a concatenation connective ; and write ee' for $e; e'$. To describe cases of deadlock mentioned above in disambiguating an expression e, with l occuring to its left and r to its right, let us define e to be *l, r-stuck* if for every $r' \in E$, $[l, e, r] = [l, e, rr']$. We will assume that unambiguous formulas are left alone

(A1) for all $\varphi \in \Phi$ and $l, r \in E$, $\delta(\varphi) = \{\varphi\}$ and $[l, \varphi, r] = \varphi$

from which it follows that every $\varphi \in \Phi$ is l, r-stuck (for all $l, r \in E$). Next, let us weaken the function $[\cdot,\cdot,\cdot]$ into a relation $D \subseteq E \times E \times E \times \Phi$, given by

$$D(l, e, r, \varphi) \quad \text{iff} \quad [l, e, r] = \varphi \ \text{ or } \ (e \text{ is } l, r\text{-stuck and } \varphi \in \delta([l, e, r])) \ .$$

Note that the first disjunct would be subsumed by the second (and can therefore be eliminated) if, in addition to (A1), $[\cdot,\cdot,\cdot]$ is *right-monotonic* in the sense that for all $l, e, r \in E$,

$$[l,e,r] \in \Phi \quad \text{implies} \quad (\forall r' \in E)\ [l,e,r] = [l,e,rr'] \ .$$

For now, however, let us refrain from making such potentially problematic assumptions about $[\cdot,\cdot,\cdot]$. On the other hand, let us assume that for all $l, r \in E$, disambiguation by $[l,\cdot,r]$ sharpens that by δ

(A2) for all $e \in E$, $\{[l,e,r] : l,r \in E\} \cap \Phi \subseteq \delta(e)$.

Next, let us pair up sequences of expressions in E with unambiguous formulas in Φ disambiguating those expressions as follows. We will call a finite sequence $\varphi_1 \cdots \varphi_n \in \Phi^*$ a *fully disambiguated alternative (fda) to* a sequence $e_1 \cdots e_m$ in E^* if $n = m$ and there is some $\overline{r} \in E^*$ such that for every $i \in \{1,\ldots,n\}$,

$$D(e_1 \cdots e_{i-1},\ e_i,\ e_{i+1} \cdots e_n\overline{r},\ \varphi_i) \ ,$$

where the empty sequence of expressions in E is, by convention, identified with a distinguished element $\top$ in Φ ($\subseteq E$), and the parenthesization in $e_1e_2 \cdots e_n$ is to the left: $(\cdots(e_1e_2)\cdots e_n)$. Observe that the non-determinism in fda's arises not only through δ (via D), but also through guessing a continuation $\overline{r}$.[1] Now, let State be the set of all pairs $(\overline{e},\overline{\varphi})$ such that $\overline{\varphi}$ is an fda to $\overline{e}$. These states $((\overline{e},\overline{\varphi}),(\overline{e'},\overline{\varphi'}))$ undergo transitions labeled by expressions $e \in E$ as follows:

$$(\overline{e},\overline{\varphi}) \overset{e}{\rightsquigarrow} (\overline{e'},\overline{\varphi'}) \quad \text{iff} \quad \overline{e'} = \overline{e}e \ \text{ and } \ (\exists\varphi)\ \overline{\varphi'} = \overline{\varphi}\varphi \ ,$$

as well as an equivalence relation

$$(\overline{e},\overline{\varphi}) \overset{\diamond}{\rightsquigarrow} (\overline{e'},\overline{\varphi'}) \quad \text{iff} \quad \overline{e'} = \overline{e} \ ,$$

supporting a jump to a different interpretation $\overline{\varphi'}$ of $\overline{e}$.[2] In short, a pair of disambiguation functions δ and $[\cdot,\cdot,\cdot]$ induces a set State of states, with a labeled transition relation $\rightsquigarrow \subseteq \mathsf{State} \times (E + \{\diamond\}) \times \mathsf{State}$.

3 Logical consequence and ambiguous extensions

Next, let us factor in the meaning of formulas of Φ by assuming a logical consequence relation $\rhd$ on Φ — i.e., a relation on $\Phi^* \times \Phi$ such that intuitively,

$$\varphi_1 \cdots \varphi_n \rhd \varphi \quad \text{iff} \quad \varphi \text{ is a consequence of } \varphi_1,\ldots,\varphi_n \ .$$

To explore how $\rhd$ might be extended to ambiguous expressions, let us

(i) combine $\rhd$ with State and $\rightsquigarrow$ to form a *$(E,\Phi$-$)$Kripke model* $\langle \mathsf{State}, \rightsquigarrow, V\rangle$, where the *valuation* $V : \Phi \to Power(\mathsf{State})$ is defined by

$$V(\varphi) \;=\; \{(\overline{e},\overline{\varphi}) \in \mathsf{State} : \overline{\varphi} \rhd \varphi\}$$

(ii) generate *$\mathcal{L}$-formulas* A from formulas $\varphi \in \Phi$ and expressions $e \in E$ as follows

$$A \quad ::= \quad \varphi \mid \langle e\rangle A \mid \diamond A \mid \neg A \mid A \wedge B$$

[1] The totality of such $\overline{r}$'s (supporting the interpretation $\overline{\varphi}$ of $\overline{e}$) underlies an *abduction* (Peirce 1955) of $\overline{\varphi}$ from $\overline{e}$, relative to $[\cdot,\cdot,\cdot]$ and δ.

[2] The input/output $(\overline{e},\overline{\varphi})$ concept of state analyzed here is extensional, and is to be contrasted say, with a notion of state that keeps track of all interpretations of $\overline{e}$ that have been tried.

and

(iii) interpret an $\mathcal{L}$-formula A relative to a Kripke model $\langle \mathsf{State}, \rightsquigarrow, V\rangle$ and a state $(\overline{e}, \overline{\varphi})$ according to

$$\begin{array}{rcl}
(\overline{e}, \overline{\varphi}) \models \varphi & \text{iff} & (\overline{e}, \overline{\varphi}) \in V(\varphi) \quad (\text{i.e., } \overline{\varphi} \rhd \varphi) \\
(\overline{e}, \overline{\varphi}) \models \langle e\rangle A & \text{iff} & \text{for some } \varphi \text{ such that } (\overline{e}e, \overline{\varphi}\varphi) \in \mathsf{State}, \\
 & & (\overline{e}e, \overline{\varphi}\varphi) \models A \\
(\overline{e}, \overline{\varphi}) \models \Diamond A & \text{iff} & \text{for some } \overline{\psi} \text{ such that } (\overline{e}, \overline{\psi}) \in \mathsf{State}, \\
 & & (\overline{e}, \overline{\psi}) \models A \\
(\overline{e}, \overline{\varphi}) \models \neg A & \text{iff} & \text{not } (\overline{e}, \overline{\varphi}) \models A \\
(\overline{e}, \overline{\varphi}) \models A \wedge B & \text{iff} & (\overline{e}, \overline{\varphi}) \models A \text{ and } (\overline{e}, \overline{\varphi}) \models B\ .
\end{array}$$

Note that $\mathcal{L}$ is written instead of the more correct $\mathcal{L}(E, \Phi)$, and the subscript $\langle \mathsf{State}, \rightsquigarrow, V\rangle$ on $\models$ is suppressed, so as not to clutter the notation.

But how does any of this help us get a grip on a notion of logical consequence on E? To see how, let us assume also that there is an "absurd" formula $\bot \in \Phi$ such that

(A0) for every $\varphi \in \Phi$, there is a formula $\sim\varphi \in \Phi$ satisfying

$$\overline{\varphi} \rhd \varphi \quad \text{iff} \quad \overline{\varphi} \sim\varphi \rhd \bot\ ,$$

for all $\overline{\varphi} \in \Phi^*$.

I have been careful to write $\sim\varphi$ instead of $\neg\varphi$, as the latter is an $\mathcal{L}$-formula that should not be confused with any in Φ.[3] In particular, assuming there is a formula $\top \in \Phi$ such that for every $\overline{\varphi} \in \Phi^*$, $\overline{\varphi} \rhd \top$, we should be careful to distinguish $\bot$ from $\neg\top$. Whereas no state may satisfy $\neg\top$, it is clear from (A0) that $\bot$ is satisfied by many states. Indeed, (A0) amounts (in the presence of (A1)) to

$$\begin{array}{rcl}
\varphi_1 \cdots \varphi_n \rhd \varphi & \text{iff} & (\emptyset, \emptyset) \models [\varphi_1] \cdots [\varphi_n][\sim\varphi]\bot \\
 & \text{iff} & (\emptyset, \emptyset) \models \langle\varphi_1\rangle \cdots \langle\varphi_n\rangle\langle\sim\varphi\rangle\bot\ ,
\end{array}$$

suggesting a formalization of the assertion that an expression $e \in E$ is a logical consequence of $e_1 \ldots e_n \in E^*$ as $[e_1] \cdots [e_n][\sim e]\bot$ or $\langle e_1\rangle \cdots \langle e_n\rangle\langle\sim e\rangle\bot$, for some extension of $\sim\cdot$ to E. Other plausible candidates include $\Box[e_1] \cdots [e_n][\sim e]\bot$ and $\Diamond\langle e_1\rangle \cdots \langle e_n\rangle\langle\sim e\rangle\bot$.[4] Note that $[\sim e]\bot$ might be expressed as $\neg(\neg\bot \wedge \langle e\rangle\bot)$, and $\langle\sim e\rangle\bot$ as $\neg(\neg\bot \wedge [e]\bot)$.

To motivate $\mathcal{L}$ further, recall the definition of a *bisimulation* between (possibly identical) Kripke models $M = \langle \mathsf{State}, \rightsquigarrow, V\rangle$ and $M' = \langle \mathsf{State}', \rightsquigarrow', V'\rangle$ — namely, a binary relation $R \subseteq \mathsf{State} \times \mathsf{State}'$ such that whenever aRa',

(a) for all $\varphi \in \Phi$, $a \in V(\varphi)$ iff $a' \in V'(\varphi)$,

(b) for every $l \in E + \{\Diamond\}$ and $b \in \mathsf{State}$ such that $a \overset{l}{\rightsquigarrow} b$, there exists $b' \in \mathsf{State}'$ such that $a' \overset{l}{\rightsquigarrow}{}' b'$ and bRb',

and (conversely)

[3] More generally, it should go without saying that none of the non-atomic $\mathcal{L}$-formulas $\langle e\rangle A$, $\Diamond A$, $\neg A$ or $A \wedge B$ belong to E.

[4] The relational interpretation of consequence here builds on ideas described (for example) in chapter 16 of van Benthem 1991, a crucial addition being the distinction between $\bot$ and $\neg\top$.

(c) for every $l \in E + \{\Diamond\}$ and $b' \in \mathsf{State}'$ such that $a' \overset{l}{\rightsquigarrow}' b'$, there exists $b \in \mathsf{State}$ such that $a \overset{l}{\rightsquigarrow} b$ and bRb'.

Now, a natural notion of equivalence between states a and a' is that of *bisimilarity* $\underline{\leftrightarrow}_{MM'}$,

$$a \underline{\leftrightarrow}_{MM'} a' \quad \text{iff} \quad \text{there is a bisimulation relating } a \text{ with } a' \ .$$

As will come as no surprise to readers familiar with say, Hennessy and Milner 1985, bisimilarity can (under suitable assumptions) be captured by modifying clause (a) of the definition above of a bisimulation so that the set Φ is enlarged to $\mathcal{L}$.

More precisely, given a state $(\overline{e}, \overline{\varphi})$ of M and a state $(\overline{e'}, \overline{\varphi'})$ of M', let us define $M, (\overline{e}, \overline{\varphi}) \equiv_{\mathcal{L}} M', (\overline{e'}, \overline{\varphi'})$ to mean that the states satisfy the same $\mathcal{L}$-formulas — that is, for every $\mathcal{L}$-formula A,

$$(\overline{e}, \overline{\varphi}) \models_M A \quad \text{iff} \quad (\overline{e'}, \overline{\varphi'}) \models_{M'} A \ .$$

Theorem 1. *Let $\delta, [\cdot,\cdot,\cdot], \rhd$ and $\delta', [\cdot,\cdot,\cdot]', \rhd'$ be triples satisfying (A1) and (A2), and inducing Kripke models $M = \langle \mathsf{State}, \rightsquigarrow, V \rangle$ and $M' = \langle \mathsf{State}', \rightsquigarrow', V' \rangle$, respectively. If*

(†) *for every $e \in E$, $\delta(e)$ and $\delta'(e)$ are finite sets,*

then for all $(\overline{e}, \overline{\varphi}) \in \mathsf{State}$ and $(\overline{e'}, \overline{\varphi'}) \in \mathsf{State}'$,

$$(\overline{e}, \overline{\varphi}) \underline{\leftrightarrow}_{MM'} (\overline{e'}, \overline{\varphi'}) \quad \textit{iff} \quad M, (\overline{e}, \overline{\varphi}) \equiv_{\mathcal{L}} M', (\overline{e'}, \overline{\varphi'}) \ .$$

Note. Without (†), Theorem 1 can be established by beefing up $\mathcal{L}$ with infinitary conjunction.

Turning now to the logic of $\mathcal{L}$, define an $\mathcal{L}$-formula A to be $\mathcal{L}(\rhd)$-*valid* if for every pair of functions δ and $[\cdot,\cdot,\cdot]$ meeting (A1) and (A2), A holds at every state of the $\mathcal{L}$-model induced by $\delta, [\cdot,\cdot,\cdot]$ and $\rhd$. Now, assuming $\rhd$ satisfies

$$(\text{Ref}) \ \frac{}{\varphi \rhd \varphi} \qquad (\text{Weak}) \ \frac{\overline{\varphi} \rhd \varphi}{\overline{\varphi}\psi \rhd \varphi} \quad \frac{\overline{\varphi} \rhd \varphi}{\psi\overline{\varphi} \rhd \varphi} \qquad (\text{Cut}) \ \frac{\overline{\varphi} \rhd \psi \qquad \overline{\varphi}\psi \rhd \varphi}{\overline{\varphi} \rhd \varphi} \ ,$$

it follows that for all $\varphi_1, \ldots, \varphi_n, \varphi \in \Phi$,

$$\varphi_1 \cdots \varphi_n \rhd \varphi \quad \text{iff} \quad (\varphi_1 \wedge \cdots \wedge \varphi_n) \supset \varphi \ \text{ is } \mathcal{L}(\rhd)\text{-valid}$$

(where, as usual, $A \supset B$ abbreviates $\neg(A \wedge \neg B)$). Call an $\mathcal{L}$-formula A $\mathcal{L}$-*valid* if A is $\mathcal{L}(\rhd)$-valid for every $\rhd$ satisfying (Ref), (Weak), (Cut) and $\rhd\top$. That is, let us add to (A1) and (A2) the assumption

(A3) the rules (Ref), (Weak) and (Cut) are sound in $\rhd$, and $\rhd\top$.

Theorem 2. *The set of $\mathcal{L}$-valid formulas is decidable. Indeed, $\mathcal{L}$ has the finite model propery.*

4 Discussion

Let us close by considering two widely held views about ambiguity: (i) that it requires a meta-level analysis (as opposed to a reduction via say, disjunction; see, for example, van Deemter 1996), and (ii) that there is an element of defeasibility or revision in it. Now, the language $\mathcal{L}$ provides (i) a meta-language distinct from both Φ and E, that (ii) expresses a very simple form of revision, described by the $\stackrel{\diamond}{\rightsquigarrow}$ transitions underlying $\diamond$. More complicated variations of $\diamond$ are easy to dream up, and are obvious subjects of investigation — perhaps under special assumptions on $[\cdot,\cdot,\cdot]$. For example, assuming there are bounds on (right) look-ahead and on (left) memory in $[\cdot,\cdot,\cdot]$, the sequences that make up states can be truncated. Presumably, however, *some* memory and look-ahead must be allowed, if the notion of discourse is to play a constructive role in interpretation/disambiguation.

Speaking of which, the reader may well ask: how does $\mathcal{L}$ relate to *Discourse Representation Theory* (DRT, Kamp and Reyle 1993) or (for that matter) any of DRT's various competitors (e.g., Ranta 1994)? An important feature of the DRS construction algorithm that $\mathcal{L}$ addresses is its non-determinism (arising, for example, from the rule of optional distribution in page 328 of Kamp and Reyle 1993, not to mention anaphora resolution). Notice that smuggled into assumption (A3) above is the monotonic rule (Weak) on the consequence relation $\rhd$ on Φ; this rule is at odds with variants of DRT that allow for reassignment of values to variables (necessitated by *total* variable assignments). While there are good reasons to recognize non-monotonicity, it seems to me there is no need to insist that $\rhd$ be non-monotonic, as long as E is brought in as a language different from Φ, with non-monotonicity introduced through the (non-deterministic) leap from E to Φ. In this way, we can keep Φ logically pristine, subject to familiar model-theoretic and proof-theoretic analyses. (It is perhaps worth noting that persistence of variable assignments is crucial to the reconciliation between DRT and Ranta's *Type-Theoretical Grammar* attempted in Fernando 1997.)

Just how general then is the present study of ambiguity via $\mathcal{L}$? The line pursued and developed in a rather abstract manner here is only one of two strategies for dealing with ambiguity mentioned in Asher and Fernando 1997 — the other involving underspecified representations. In either case, more attention must be paid to the form of E and Φ (some steps towards which are taken in Fernando 1995).

References

N. Asher and T. Fernando. Labeling representations for effective disambiguation. In *Proc. Second International Workshop on Computational Semantics*. Tilburg, The Netherlands, 1997.

Johan van Benthem. *Language in Action: Categories, Lambdas and Dynamic Logic*. North-Holland, Amsterdam, 1991.

Kees van Deemter. Towards a logic of ambiguous expressions. In K. van Deemter and S. Peters, editors, *Semantic Ambiguity and Underspecification*, CSLI Lecture Notes Number 55, Stanford, 1996.

Tim Fernando. Ambiguity under changing contexts. Preliminary version presented in *Mathematics of Language 4* (1995); to appear in *Linguistics and Philosophy*.

Tim Fernando. A type reduction from proof-conditional to dynamic semantics. Extended abstract presented in *Formal Grammar* (Aix-en-Provence), August 1997.

M. Hennessy and R. Milner. Algebraic laws for nondeterminism and concurrency. *J. Assoc. Computing Machinery*, 32(1), 1985.

H. Kamp and U. Reyle. *From Discourse to Logic*. Kluwer, Dordrecht, 1993.

Charles Sanders Peirce. Abduction and induction. In J. Buchler, editor, *Philosophical Writings of Peirce*. Dover Books, New York, 1955.

Aarne Ranta. *Type-Theoretical Grammar*, Oxford University Press, Oxford, 1994.

A decidable linear logic for transforming DRSs in context

Tsutomu Fujinami[1]
IMS, University of Stuttgart

Abstract

We present a decidable linear logic for encoding and transforming Discourse Representation Structures (DRSs) in context. The logic is a particular fragment of intuitionistic propositional linear logic (ILL), slimed down by not allowing for any occurrence of exponential, !, in the consequence and slightly enriched by allowing to combine commutative and non-commutative multiplicative connectives. Its model is given as processes with geometric structure, which can also be seen as proofnets explicit with respect to location and direction. We show that the model is rich enough to encode DRSs and that the proof search is bound to be finite and terminates.

1 Introduction

The construction of Discourse Representation Structures (DRSs) has been studied by several researchers, e.g., [?]. The research aims to know how DRSs can be constructed from sentences. Inspired by the research, we study the issue of transforming DRSs. Our research is motivated by a practical problem. Discourse Representation Theory (DRT) [?] is currently applied to building application systems such as speech translation system [?]. In the case of translation, the meaning of a source language sentence is represented as a DRS, which is transformed into another DRS appropriate to generate a target sentence. The question in building such a system is this: How can one be assured that the transformation will always terminate, however it succeeds or fails? Our goal is to answer the question positively.

To answer the question, we formalise the transformation of DRSs in a logic. This gives us at least two advantages. First, the problem of termination is reduced to the decidability problem. Second, eliminating redundant transformation steps becomes equivalent to cut elimination. Given these incentives, we turn to linear logic among many logics for two reasons. For one reason, linear logic gives us a natural setup to model transformation owing to its resource sensitiveness. For anoher, its semantics is directly related to computation. The second point is important because we consider DRSs as proof or program to be typed in the logic. In this setting, we can regard the transformation as proof search.

One can recognise in our work several sources that help to develop our ideas. To encode DRSs, we follow the approach advocated by [?] in that we keep the description of DRSs *flat*. The technique helps us to keep our logic propositional because we do not need to consider nested structures. To represent a DRS as a

[1]The work is funded by the German Federal Ministry of Education, Science, Research and Technology (BMBF) in the framework of the Verbmobil project (Grant No. 01 IV 701 N3).

set of terms, we follow the glue language approach proposed by [?] in that we glue terms using the multiplicative connective, $\otimes$. The relation between terms and types is as with [?], but we employ as term a variant of the π-calculus [?] to encode DRSs, which is typed by our fragment of linear logic. The relation between the π-calculus and linear logic is as proposed by [?], but we simplify their encoding to fit the π-calculus terms into interaction nets [?].

Overview: We go through three tasks. First, we design a decidable fragment of linear logic, then specify its model, into which DRSs can be encoded. We finally prove the decidability. Due to the limited space, we cannot explain the speach-translation system we are developing and our approach to translation in Verbmobil project. Readers are referred to [?] and [?].

2 The decidable fragment

It is known that multiplicative linear logic (MLL) is decidable. MLL is however too restrictive to specify the transformation in context because a formula can only be referred to once while we would like to refer to formulas more than once if they define part of contexts. By context, we mean a part of DRSs that is not transformed itself but affects the way some other parts are transformed. We have to therefore extend the fragment with the exponential, !, but then we face the problem that the decidability of multiplicative-exponential linear logic (MELL) is unknown [?].

We observe that the source of difficulty is in allowing for both unlimited supply and consumption of resources. For our purpose, however, the latter is not necessary because transformed DRSs do not need to be referred to repeatedly. Once we restrict the use of exponential to the antecedent, the decidability of the fragment is trivial. Reusable resources are referred to as many times as a demand arises and will be erased out when they are not needed anymore. The second elaboration is made on multiplicative conjunction, $\otimes$. The connective is usually commutative or non-commutative exclusively, but we allow to combine both kinds of connectives so that we can specify both set and list data structures.

Table ?? shows our fragment of linear logic. The fragment is basically the (associative) Lambek Calculus as presented in [?], but it is extended by combining both the commutative connective, $\otimes$, and the non-commutative one, $\oslash$. Note that the exchange rule is applicable to the commutative connective only. The weakening is as usual, but the contraction rule only allows to generate A without the exponential. With the side condition that A should be neither in Γ nor in Δ, the rule prohibits the logic from generating a number of unused $!A$s. We also exclude the rules for dereliction (Table ??). The same effect by the Dereliction Left rule can be derived in our logic with the Contraction, $\otimes$ Left, and Weakening rules. The Dereliction Right rule does not conform to our idea of eliminating any occurrences of the exponential in the consequent.

The linear implication, $\multimap$, is defined as the non-directional version of $\backslash$ and $/$, but the definition is not included in the table to save the space. Note that the logic is weaker than classical intuitionistic logic because no formulas in the form of $!A \multimap B$ can be constructed as they lead to an occurrence of $!A$ in consequence by the $\multimap$ Left rule.

Exchange	$\dfrac{\Gamma, A \otimes B, \Delta \vdash C}{\Gamma, B \otimes A, \Delta \vdash C}$		
Weakening	$\dfrac{\Gamma, \Delta \vdash B}{\Gamma, !A, \Delta \vdash B}$	$\dfrac{\Gamma, !A \otimes A, \Delta \vdash B}{\Gamma, !A, \Delta \vdash B}$	Contraction ($A \notin \Gamma, \Delta$)
Identity	$\dfrac{}{A \vdash A}$	$\dfrac{\Gamma \vdash A \quad \Pi, A, \Delta \vdash B}{\Pi, \Gamma, \Delta \vdash B}$	Cut
1 Left	$\dfrac{\Gamma, \Delta \vdash A}{\Gamma, \mathbf{1}, \Delta \vdash A}$	$\dfrac{}{\vdash \mathbf{1}}$	**1** Right
$\otimes$ Left	$\dfrac{\Gamma, A, B, \Delta \vdash C}{\Gamma, A \otimes B, \Delta \vdash C}$	$\dfrac{\Gamma \vdash A \quad \Delta \vdash B}{\Gamma, \Delta \vdash A \otimes B}$	$\otimes$ Right
$\oslash$ Left	$\dfrac{\Gamma, A, B, \Delta \vdash C}{\Gamma, A \oslash B, \Delta \vdash C}$	$\dfrac{\Gamma \vdash A \quad \Delta \vdash B}{\Gamma, \Delta \vdash A \oslash B}$	$\oslash$ Right
$\backslash$ Left	$\dfrac{\Gamma \vdash A \quad \Pi, B, \Delta \vdash C}{\Pi, \Gamma, A \backslash B, \Delta \vdash C}$	$\dfrac{A, \Gamma \vdash B}{\Gamma \vdash A \backslash B}$	$\backslash$ Right
$/$ Left	$\dfrac{\Gamma \vdash A \quad \Pi, B, \Delta \vdash C}{\Pi, B/A, \Gamma, \Delta \vdash C}$	$\dfrac{\Gamma, A \vdash B}{\Gamma \vdash B/A}$	$/$ Right

Table 1: Sequent calculus formalisation of the logic

Dereliction Left	$\dfrac{\Gamma, A \vdash B}{\Gamma, !A \vdash B}$	$\dfrac{!\Gamma \vdash A}{!\Gamma \vdash !A}$	Dereliction Right

Table 2: The dereliction rules (Not in our fragment)

3 The model

The model is essentially proofnets [?] explicit with respect to location and direction. It can also be seen as π-calculus terms [?] enriched with geometric structure. Table ?? shows the relation between proofnets and π-terms. The explanation is in order. We mark propositions in the antecedent with $\top$ and assign them an action such that it imports a datum of the type indicated by the proposition. We also assume that any actions composing a process occur at a particular location and write the location together with the proposition, e.g., $x : A$, meaning that the action occurs at x. The propositions in the consequence are on the other hand left unmarked and assigned exporting actions. In the π-translation, $\overline{x}\langle a \rangle$ means the action such as exporting the datum a at x and $y(a)$ the action such as importing the datum a at y. (We assume in the table that a_i is a datum of the type A and b a datum of the type B.)

Terms assigned to composite types are almost as proposed in [?], but we retain the geometric structure. The term assigned to $y : A \oslash B$ is for example expressed as a tree, $\langle\, \overline{y}\langle x\rangle, \overline{x}\langle a\rangle, \overline{x}\langle b\rangle \,\rangle$, where $\overline{y}\langle x\rangle$ is the mother node, $\overline{x}\langle a\rangle$ the left daughter, and $\overline{x}\langle b\rangle$ the right daughter. The term can be seen as defining a complex action such that a and b are exported through x, which is accessible through y.

	Proofnet	π-translation
Axiom	$\dfrac{}{x : A \quad y : A^{\top}}\ (x \neq y)$	$[\overline{x}\langle a\rangle \cdots y(a)]$
Cut	$\underline{x : A \quad x : A^{\top}}$	$[\nu x(\overline{x}\langle a_1\rangle \cdots x(a_2))]$
$\oslash(\otimes)$-Negative	$\dfrac{x : B^{\top} \quad x : A^{\top}}{y : (A \oslash B)^{\top}}$	$\langle\, y(x), x(b), x(a) \,\rangle$
$\otimes$-Negative	$\dfrac{x : A^{\top} \quad x : B^{\top}}{y : (A \otimes B)^{\top}}$	$\langle\, y(x), x(a), x(b) \,\rangle$
$\oslash$-Positive	$\dfrac{x : A \quad x : B}{y : A \oslash B}$	$\langle\, \overline{y}\langle x\rangle, \overline{x}\langle a\rangle, \overline{x}\langle b\rangle \,\rangle$
$\backslash$-Negative	$\dfrac{x : A \quad x : B^{\top}}{y : (A\backslash B)^{\top}}$	$\langle\, y(x), \overline{x}\langle a\rangle, x(b) \,\rangle$
$\backslash$-Positive	$\dfrac{x : B \quad x : A^{\top}}{y : A\backslash B}$	$\langle\, \overline{y}\langle x\rangle, \overline{x}\langle b\rangle, x(a) \,\rangle$
$/$-Negative	$\dfrac{x : A^{\top} \quad x : B}{y : (A/B)^{\top}}$	$\langle\, y(x), x(a), \overline{x}\langle b\rangle \,\rangle$
$/$-Positive	$\dfrac{x : B^{\top} \quad x : A}{y : A/B}$	$\langle\, \overline{y}\langle x\rangle, x(b), \overline{x}\langle a\rangle \,\rangle$
!-Delete	$\dfrac{}{x : (!A)^{\top}}$	**0**
!-Read(left)	$\dfrac{x : A^{\top} \quad y : (!A)^{\top}}{y : (!A)^{\top}}$	$\langle\, !\nu y.y(a_i), x(a_i), !\nu y.y(a_{i+1}) \,\rangle$

Table 3: The proofnet and π-translation

The enriched π-calculus with geometry enables us to encode DRSs. Let us take up as an example a relation, $r(a, b)$. The two place relation r is regarded as a process such that it takes two data, a and b, from left-hand side at s to yield r to the right and is encoded as $\langle\, \overline{u}\langle t\rangle, \langle\, t(s), s(y), s(x) \,\rangle, \overline{t}\langle r\rangle \,\rangle$, where we assume that the interaction occurs at t accessible through u. We employ the non-commutative connective, $\oslash$, to type the process and express its type as $R/(A \oslash B)$, assuming that the relation r is of type R, x of type A, and y of type B. The objects a and b to fill the argument are regarded as an action such as exporting a or b. They are encoded as $\overline{v}\langle a\rangle$ and $\overline{w}\langle b\rangle$ and are typed as A and B, respectively. These three (sub)processes comprise the process encoding $r(a,b)$, bound altogether. For typing the process, we employ the commutative connective, $\otimes$, to glue types and express the type as $R/(A \oslash B) \otimes A \otimes B$.

4 The proof search

The above model is identical to proofnets when the direction and location are suppressed. For instance, the above process encoding $r(a,b)$ can be seen as a proofnet connected by two id-links indicated by sharing the same symbols, a and b, when x is replaced by a and y by b. We can therefore employ the proofnet technology to construct proofs.

The procedure is based on [?], consisting of four steps. We first form a tree whose edges are decorated with formulas. We then connect every pair of leaf nodes whose edges are decorated by dual atomic formulas. At this step, one can duplicate exponential parts untill all the leaf nodes whose edges are decorated with a positive atomic formula, are paired with a node whose edge is decorated with a negative formula. In the next step, we ensure that there should be no crossing between pairs. If there is a cross, we try to uncross the graph by exchanging a left and right subpart where the connective is commutative.

The graph is finally checked against a criteria, which is in essence the same as the colouring proposed in [?], but tuned up for refutation. For the sake of explanation, we call connected leaf nodes id-node. When colouring nets, subnets are coloured in the same colour as their parent if the parent is of conjunctive type, but either subnet has to be coloured differently if it is of disjunctive type. The wrong configuration can then be detected if both edges of an id-node are coloured the same or if there exist two id-nodes whose edges are coloured identically. Because the number of pairs is finite and the graph can be coloured in finite steps, the proof search always terminates.

5 Conclusion

We presented a fragment of linear logic and define a model for it. The model is the π-calculus enriched with geometric structure and expressive enough to encode DRSs. The technique is to encode semantic objects bit by bit and to glue them together, using the commutative connective, $\otimes$. There is a proof search procedure which terminates, however the search succeeds or fails.

In our setting, translation rules are encoded as a reusable process and the proof search can be seen as translation procedure. In our logical approach to translation, eliminating redundant transformation steps becomes equivalent to cut elimination. The structure found in proofnets will also be useful for selecting the best translation among many candidates, e.g. the flatter the structure is, the better the translation is.

Abrusci, V. M.: 1996, Lambek calculus, cyclic multiplicative-additive linear logic, noncommutative multiplicative-additive linear logic: Language and sequent calculus, in V. M. Abrusci and C. Casadio (eds.), *Proceedings of 1996 Roma Workshop on Proofs and Linguistic Categoris*, pp 21–48

Bellin, G. and Scott, P. J.: 1994, On the π-calculus and linear logic, *Theoretical Computer Science* 135(1), 11–65

Buschbeck-Wolf, B. and Dorna, M.: 1997, Using hybrid methods and resources in semantic-based transfer, in *Proceedings of the 2nd International Conference on Recent Advances in Natural Language Processing*

Copestake, A., Flickinger, D., Malouf, R., Riehemann, S., and Sag, I.: 1995, Translation using Minimal Recursion Semantics, in *6th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI'95)*, Leuven, Belgium

Dalrymple, M., Lamping, J., and Saraswat, V.: 1993, LFG semantics via constraints, in *Proceedings of the 6th Meeting of the European Association for Computational Linguistics*

Dorna, M. and Emele, M. C.: 1996, Semantic-based transfer, in *Proceedings of Coling '96*, pp 316–321

Kamp, H. and Reyle, U.: 1993, *From Discourse to Logic: Introduction to Modeltheoretic Semantics of Natural Language, Formal Logic and Discourse Representation Theory*, Dordrecht: Kluwer

Kay, M., Gawron, J. M., and Norvig, P.: 1994, *Verbmobil - a translation system for face-to-face dialog*, No. 33 in CSLI Lecture Notes

Lafont, Y.: 1995, From proof-nets to interaction nets, in J.-Y. Girard, Y. Lafont, and L. Regnier (eds.), *Advances in Linear Logic*, pp 225–247, Cambridge University Press

Lincoln, P.: 1995, Deciding provability of linear logic formulas, in J.-Y. Girard, Y. Lafont, and L. Regnier (eds.), *Advances in Linear Logic*, pp 109–122, Cambridge University Press

Milner, R., Parrow, J., and Walker, D.: 1992, A calculus of mobile processes, parts I and II, *Information and Computation* 100, 1–40 and 41–77

Muskens, R.: 1996, Combining Montague semantics and discourse representation, *Linguistics and Philosophy* 19, 143–186

Roorda, D.: 1991, *Resource Logics: Proof-theoretical Investigations*, Ph.D. thesis, University of Amsterdam, Amsterdam

Questions of identity[1]

Jelle Gerbrandy

Introduction

This article is about the interpretation of quantifiers in epistemic contexts, and the closely related notion of what it means for two objects in different possible worlds to be identical.

I will give arguments for several claims. The first claim is that the definition of identity between objects across epistemically possible worlds as being given by the identity of those objects themselves leads to empirical as well as conceptual problems. Recent examples of such a view on identity are the theory of questions of Groenendijk and Stokhof (1997) and the semantics for quantified modal logic of Groenendijk et al. (1996). Secondly, I will argue that these problems can be circumvented by taking trans-world identity to be a notion that is external to the possible worlds themselves (by some sort of counterpart theory, or by a set of individual concepts). This raises the old question what exactly this notion of identity is. I will argue by way of examples that there is no single notion of trans-world identity, but that the way we speak about objects depends on contextual factors.

In this paper, I will concentrate mostly on the analysis of questions and of 'knowing who,' but the points raised here are also relevant to issues related to *de re* knowledge and belief and the interaction of epistemic 'might' and quantifiers. I will address these and other issues in a more extended version of this paper.

Possibilities and information states.

Possible world semantics has turned out to be a useful tool for the analysis of intensional expressions, e.g. of sentences about necessity, knowledge or belief, and of questions. In this article, I will concentrate on the use of possible words semantics to interpret epistemic modal operators, and I will focus in particular on the semantics of 'knowing who' and of questions.

To interpret a language, possible worlds need to have a certain minimal structure: we need to know in each possible world what the predicates, constants and other lexical items of the language refer to. For the purposes of this paper, in which the object language is that of predicate logic, this means that possible worlds should at least contain as much structure as a first-order predicate logical model:

Definition 1 (possibilities and states)

A (epistemic) possibility w for a language $\mathcal{L}$ is a (first-order) model (D_w, I_w), where D_w is a set (called the domain of w), and I_w is an interpretation function that assigns to each non-logical constant of $\mathcal{L}$ an interpretation.

An epistemic state is a set of possibilities. □

[1]ILLC/Department of Philosophy, Amsterdam, gerbrand@illc.uva.nl. I would like to thank Maria Aloni, Henk Zeevat, Jeroen Groenendijk, Paul Harrenstein and Paul Dekker for discussion and comments. None of them wholly agree with the contents of this paper. Many of the ideas in this paper can be found in the literature on the subject and I have tried to give credit wherever possible, but I am not sure whether I have succeeded.

The information (knowledge, beliefs) of an agent are modeled by an information state. An information state contains all and only those possibilities that are compatible with what that agent knows; it consists of those models that, given the information of the agent in question, may picture the world correctly. If σ is the information state of some agent a that represents the *knowledge* of a, then we can assume that there is a possibility $w \in \sigma$ that represents 'the real world.'

The analysis of questions and of 'knowing who' that I will concentrate on is that of Groenendijk and Stokhof (1984, 1997). In their analysis, the meaning of a question is given by the set of its complete answers; answers are identified with propositions, i.e. sets of possibilities; and a complete answer to the question 'Who VP?' is represented by the set of all worlds in which the extension of VP is the same. In other words, a complete answer to the question 'Who VP?' is given by a specification of the set of objects that have the property expressed by the VP. A sentence of the form 'a knows who VP' is true just in case a knows what the complete true answer to the question 'Who VP?' is, i.e. a knows who VP just in case the set of objects with the property expressed by VP in each of a's epistemic alternatives is the same as the set of those objects that have the property VP in 'the real world.'

This analysis presupposes a notion of identity between objects in different possibilities: to know if the extension of VP is 'the same' in two possibilities, we need to know what it means for two objects in different possibilities to be identical.

Identity of objects.

There are at least two ways in which identity across possibilities can be modeled. The most simple view, which is exemplified by Kripke's work on necessity and reference, simply says that two objects are identical iff they are the same object. This is the notion of identity that Groenendijk and Stokhof use in their work.

Let us use the notation $\sigma \models \phi$ for the statement that ϕ is accepted (believed, known) in information state σ, and write $\sigma \models ?xPx$ when it is known in σ who P is. Rewriting definitions using this format 'Knowing who is P' is defined as knowing exactly which objects have the property P:

- $\sigma \models ?xPx$ iff for all w and v in σ, $I_w(P) = I_v(P)$.

So, $?xPx$ is accepted in a state σ just in case the extension of the predicate P is the same set of objects in each possibility in σ. If we assume that σ is a knowledge state, then a (representation of) the real world will be among the possibilities in σ. This assumption garantees that if A is the set of objects that have the property P in 'the real world', then it is known in σ who have the property P just in case in each of the possibilities in a's information state, it holds that A is indeed the set of objects that have the property P. For example, if Superman is the object d, then Lois Lane knows who Superman is just in case d is Superman in each of the possibilities in her epistemic state.

Although taking identity across possibilities as 'given' with the objects that are in the domain of those possibilities is appealing in its simplicity, this view is not without its problems.

Consider for example an information state σ that contains all and only isomorphic copies of one single model in which there is exactly one person who is the murderer. This is a state in which one knows all the properties of the murderer (all information necessary to find him, arrest him and convict him):[1] typically a case in which one knows who the murderer is. The definitions above predict exactly the opposite: σ does not contain any information about who the murderer is (it could be any object in the domain).

Another example of a situation in which the definitions give counterintuitive predictions is a state σ that contains all models in which the object d is the unique object that is the murderer. This is a state in which one knows none of the properties of the murderer (except that he or she is the murderer): as far as the information in σ goes, the murderer could be a man, woman or child, he or she could be called Frederick Pluto Bulsara or Madonna Louise Veronica Ciccone. This seems to be a typical case of not knowing who the murderer is. Again, the definitions above predict the opposite: this state is one in which one knows who the murderer is, and in which there is just a single person who might be the murderer (namely d).

These examples show that the definition of 'knowing who VP' as 'knowing which objects have the property VP' is not correct as it stands. For the more philosophically oriented among us, this is not very surprising. The objects in the domains of the possibilities are completely independent of the properties they might have in those possibilities: for any object d and any property, there is a model in which d has that property.[2] The notion of an object that is independent of the properties it might have is reminiscent of Kant's notion of a *Ding an sich*, and philosophers from Kant to Husserl to Hintikka have argued that knowledge about the objects that 'underlie our experience' is unattainable for mere humans.[3] The definition says that it is exactly this kind of knowledge that is needed to know who someone is.

Identity between objects.

Elegant though it may be, the object-oriented view on 'knowing who' runs into both empirical and conceptual problems. At the same time, the analysis of 'knowing who VP' as knowing which objects have the property VP is intuitively appealing. Moreover, Groenendijk and Stokhof's analysis of 'knowing who' is only a small part of what is probably the most sophisticated theory of the semantics of questions that exists today, and it would be unfortunate if we had to discard this whole theory on the basis of examples such as the above.

One way to avoid the problems mentioned and at the same time keep the spirit of Groenendijk and Stokhof's analysis intact, is to re-interpret identity across possibilities. Instead of modeling identity across possibilities by taking it to be given by the objects that constitute the domains of the possibilities, we assume that some equivalence relation R over the objects in different possibilities is given, and say that an object d in one possibility is identical to an object d' in another possibility just in case dRd'.[4] I will refer to such an

[1] Presuming that the models are sufficiently rich to contain such information.

[2] To avoid confusion: Kripke's arguments do not apply here. His arguments apply to counterfactual situations and 'metaphysical' necessity, where it does seem to make sense to say that the domains of the possible worlds consists of the objects that exist in the 'real world'. Such a view will not work in epistemic contexts: consider Quine's example of Ralph, who has seen the Reverend Ortcutt on different occasions (on the beach and at a party), and believes that the man he saw on the beach is different from the man he saw at the party. There is no way to model this situation, and at the same time represent the man on the beach and the man at the party (which happen to be the same person) by the same object in the information state that models Ralph's beliefs.

[3] For a more knowledgeable discussion, see, for example, the collection Dreyfus (1982) and in particular Smith (1983).

[4] To be more precise, R should be a relation between pairs (w, d), where w is a possibility and d is an

equivalence relation as an 'individuation scheme.'

Relative to an individuation scheme R, we can interpret 'knowing who' in the following way:[5]

- $\sigma \vdash_R ?xPx$ iff for all $w, v \subset \sigma$, $I_w(P)$ is R-identical to $I_v(P)$.

The earlier definition is a special case of this one, where R identifies objects just in case they are the same object, i.e. R is 'real identity.' But, as we have seen, such an identity relation does not give the right predictions about what is known in which state. The first example that I gave above seems to show that a minimal condition on an individuation scheme is that it should identify two objects in different possibilities if they have exactly the same properties. Relative to such an individuation scheme, it holds that if σ is a state that contains any number of isomorphic copies of one single model, it is always known who VP is, which is exactly what we would expect. After all, in such a state, all the properties of the things that VP are known.

Switching Schemes.

There has been a lot of debate on the question what the right notion of trans-world identity is. I believe that with respect to epistemic possibilities, this question is not a very good one to ask. Asking what *the* identity relation is presupposes that there is only one such a relation, one single way to identify objects. I will argue that this assumption leads to wrong predictions about the semantics of wh-complements and questions. There are other examples that I cannot discuss here for lack of space – examples concerning the interaction of epistemic 'might' with quantifiers, *de re* readings of epistemic modals, and the analysis of anaphora in dynamic semantics (cf. Aloni in this volume). These examples seem to provide further evidence that there is not one single way of identifying objects across possibilities in epistemic states.

This leads to the conclusion that the quantification into modal contexts presupposes a given 'mode of individuation', which may vary in different contexts.[6]

It has often been observed (for example, in Ginzburg (1996), Boër and Lycan (1986), Carlson (1983)) that both the correctness of an answer to a question and the truth of sentences of the form 'a knows who VP' are highly context dependent: what constitutes a good answer to a question depends on the goals and interests of the questioner; and whether someone can be said to know who VP depends on contextual factors in a similar way. For example, depending on the context, all of the following sentences may express a complete answer to the question 'Who is Bill Clinton?', as well as the information that a needs so that the sentence 'a knows who Bill Clinton is' is true.

object in the domain of w. If we assume that any two possibilities have disjoint domains, we can let R be a relation between objects *simpliciter*. I will do this in the following.

[5]This definition, although it looks quite different, is in fact very close to Hintikka's analysis of 'knowing who.' Hintikka's analysis only applies to sentences of the form 'a knows who NP is', where NP is a definite description (i.e. an expression that identifies a unique object in each possibility, such as a proper name or an NP of the form 'the N'). Hintikka uses individual concepts as his method of identifying objects across possible worlds, but given Hintikka's assumptions on such a set, this is just a special case of our notion of an identification scheme. The only essential difference between this analysis and that of Hintikka is that he assumes that 'knowing who NP is' presupposes the existence of an object satisfying the description NP.

[6]This conclusion is not new. For example, Hintikka (1969), Kaplan (1979) and Kraut (1983) argue (or, at least, claim) that quantifiers range over a set of individual concepts that varies depending on the context.

(1) Bill Clinton is the president of the United States.

(2) That is Bill Clinton (pointing to him).

(3) Bill Clinton was born on august 19, 1946.

The first sentence would be a complete answer to the question who Bill Clinton is in the context of, for example, a highschool exam. If a student has the information expressed by (1), his teacher would have enough reason to say that this student knows who Bill Clinton is.[7] This does not mean, however, that the student would be able to recognize Clinton. At a fund-raising party at which Bill Clinton is present, the question who Bill Clinton is not satisfactory answered with (1); pointing him out to the questioner would be a better answer. In situations like these, knowing who Bill Clinton is, is knowing which of the people present is Bill Clinton. In a completely different situation, say at a conference of astrologers, his job or looks may be considered completely irrelevant. Instead, his date of birth would be considered much more important. In such a situation, sentence (3) would be considered a good answer to the question who Bill Clinton is, and many an astrologer would agree that he does not know who Bill Clinton is unless he knows his date of birth.

In general, it seems that when we ascribe knowledge to people by using a circumlocution of the form 'a knows who ... is,' there will be different kind of information that support such a judgment. For some purposes, knowing someone's name will be enough evidence for knowing who that person is (and stating his name a good answer to the question who he is), for other purposes, knowing where he is and what he looks like may be the kind of information needed, in other cases, it may be important what his birthdate is, etcetera.

Fortunately, we already have the tools available to model these different sorts of knowledge ascription. The only assumption we need to give up is that there is one fixed individuation scheme relative to which the quantifier $?x$ is interpreted. Relative to an individuation scheme R that identifies people by their position in society (R is a relation that holds between two objects in different worlds just in case they have the same 'position in society'; in particular, if d is the president of the United States in some possibility, and d' is the president in another possibility, then dRd'), it holds that you know who Bill Clinton is if you know that he is the president, i.e.[8]

$$\sigma \models_R ?x(x = \mathsf{Bill\ Clinton}) \text{ iff } \sigma \models (1)$$

Relative to an individuation scheme R that identifies people just in case they are born on the same day, it holds that

$$\sigma \models_R ?x(x = \mathsf{Bill\ Clinton}) \text{ iff } \sigma \models (3)$$

As an extra argument for the claim that we really cannot make do with a single individuation scheme, imagine a small room in which two people sit: a butler and a gardener. One of them is called John, the other Mary, but you do not know whether John is the butler or the gardener. The butler has committed a horrible crime; the gardener had nothing to do with it. So, you know who has done it: the butler.

[7]This example excludes the view that (1) is only a *partial* answer, because in that case, the student would not have a complete answer to the question, and thus, in the present analysis, he does not know who Bill Clinton is.

[8]Given that (1) is in fact true, and σ is a state that models the knowledge of some person, i.e. that the information reprsented in σ is in true.

On the other hand, you do not know if John is the butler or not, and so you don't know whether he has done it. The same holds for Mary. So, it seems you do not know who has done it after all: it could be either John or Mary.

We seem to have a situation here in which, in one respect, you know who has done it (namely the butler) and from another viewpoint, you don't (it could be either John or Mary). This situation can be accounted for by switching identification schemes: relative to an R in which the butler and the gardener are identified, it holds that you accept $?x(\mathsf{done\ it}(x))$, relative to a scheme in which John and Mary are identified, it holds that you do not accept that $?x(\mathsf{done\ it}(x))$.

Conclusion

Identity between objects in possibilities should not be seen as given by the objects themselves: such a view is both conceptually and empirically questionable. Instead, identity across possibilities should be taken as a non-primitive notion. This raises the question what this identity relation is. I have argued, by giving examples from wh-constructions, that the notion of trans-world identity should be seen as a context dependent notion.

I will end this paper with some general questions that I have not addressed. One issue is whether an individuation scheme should be modeled as an equivalence relation (as I have done here), or as a set of individual concepts, or even as a set of salient properties. A second question is what (if any) the general constraints on individuation schemes are (I have mentioned that such schemes should always identify objects in case they have exactly the same properties. But one could also argue that any object should be identified with at most one other object in any possibility). Given that individuation schemes are context-dependent, there is the question of where this parameter should be put. It could be a variable in the logical form of a sentence (and if so, is it introduced by the quantifiers or by the modal operators?) or a parameter in the context itself (which implies that all quantifiers and wh-terms are interpreted relative to the same individuation scheme).

References

Maria Aloni (1997) *Quantification in dynamic semantics.* This volume.

Steven E. Boër and William G. Lycan (1986) *Knowing who.* The MIT Press.

Lauri Carlson (1983) *Dialogue games.* Reidel, Dordrecht.

Hubert L. Dreyfus, ed. (1982) *Husserl, intentionality and cognitive science.* The MIT Press.

Jonathan Ginzburg (1996) *Interrogatives.* In Shalom Lappin, ed., *Handbook of contemporary semantic theory*, pages 1385–422. Blackwell, Oxford.

Jeroen Groenendijk and Martin Stokhof (1984) *Studies on the semantics of questions and the pragmatics of answers.* Jurriaans BV, Amsterdam.

Jeroen Groenendijk and Martin Stokhof (1997) *Questions.* In Johan van Benthem and Alice ter Meulen, eds., *Handbook of logic and language*, pages 1055–1124. Elsevier.

Jeroen Groenendijk, Martin Stokhof and Frank Veltman (1996) *Coreference and modality.* In Shalom Lappin, ed., *Handbook of contemporary semantic theory*, pages 179–213. Blackwell, Oxford.

Jaakko Hintikka (1969) *Semantics for propositional attitudes.* In J. W. Davis, D. J. Hockney and W. K.Wilson, eds., *Philosophical Logic*, pages 21–45.

David Kaplan (1979) *Transworld Heir Lines.* In Michael J. Loux, ed., *The possible and the actual*, pages 88–109. Cornell University Press, Ithaka and London.

Robert Kraut (1983) *There are no de dicto attitudes.* Synthese, 54:275–294.

David Woodruff Smith (1983) *Kantifying in.* Synthese, 54:261–273.

Linking sensitivity to limited distribution: The case of free choice

Anastasia Giannakidou, ILLC-Department of Philosophy
University of Amsterdam

Abstract
In this paper I propose an analysis of free choice indefinites (FCIs) in Greek as polarity items. The primary goal is to connect the constraints on the distribution of FCIs to their semantics, in favor of the more general argument that it is sensitivity that determines limited distribution in polarity items. First, I establish that the FC paradigm is distinct from negative polarity. Next, I propose a semantics of FCIs as *attributive* indefinites. Attributiveness is a modal feature imposing the requirement that FCIs be interpreted with respect to a set of epistemic i(dentity)- alternatives to the world of evaluation w_0. This interpretative requirement fails to be satified in episodic contexts, i.e contexts which involve event closure, FCIs will thus be ungrammatical there. By contrast, FCIs will be grammatical in contexts where the event variable is bound by some operator or absent altogether (habitual/generic sentences and individual-level predicates). The anti-episodicity requirement is captured in the form of an anti-licensing condition, hence allowing for anti-licensing as a theoretically available option for well-formedness conditions on certain PIs. This condition can be shown to account directly not only for the facts in Greek, but also for FCIs in (at least) Spanish and Catalan.

1 Background on polarity items

Polarity items (PIs) are expressions which cannot occur just anywhere but whose distribution is severely constrained by semantic factors. In Giannakidou 1997, I proposed to capture the limited distribution of PIs as a result of their *sensitivity:* PIs are dependent on some semantic property of the context for their proper interpretation. The definitions in (1) and (2) illustrate this view (from Giannakidou 1997):

(1) *Polarity item*
An expression a is a polarity item if the distribution of a is dependent on some semantic property β of the context of appearence.

(2) *Semantic dependency*
a is semantically dependent on β iff, for the proper interpretation of a, (i) or (ii) holds, for some relation R:
(i) $R(a, \beta)$, (ii) $\neg R(a, \beta)$

Semantic dependency is the source of sensitivity, thus of limited distribution. Clause (2) predicts two types of dependency: a positive (i) and a negative one (ii), depending on the nature of R. R may be a positive relation between PI and context (a *must* relation), in which case dependency is conceptualized as attraction, or it may be negative, a *must not* relation. In this case, dependency reflects some kind of incompatibility between PI and context. We can say, for instance, that *any students* is grammatical in (3a) with the interpretation in (3c) because there is a *must* relation between *any students* and negation. By contrast, *some students* in (3b) can only be interpreted outscoping negation as in (3c), because a *must not* relation holds between negation and this item (this is the assumption underlying the standard analysis of *some* as a positive PI):

(3) a Margo didn't see any students.
b Margo didn't see some students.
c $\exists x$ [student (x) $\wedge \neg$ saw (Margo , x)]
d $\neg \exists x$ [student (x) $\wedge$ saw (Margo, x)]

When (2i) holds we talk about *licensing*; (2ii) involves *anti-licensing*. Hence, *any students* is a licensed PI, but *some students* is an anti-licensed one. As is obvious from (3), licensing translates into a be-in-the-scope-of condition; for anti-licensing, on the other hand, no such scope condition can be invoked (rather, an *anti-scope* condition may be in order). Giannakidou 1997 was the first to formulate licensing and anti-licensing in terms of semantic dependency as above; the insight, however, that a theory of PIs should allow for negative conditions goes back to Ladusaw 1979 (see also Progovac 1994 for a syntactic implementation of this idea).

In this paper, I propose that Greek FCIs are anti-licensed PIs, and I identify *episodicity* as the crucial relation *R*. First, I show that FCIs are PIs distinct from affective PIs (APIs). Then, I give a semantics of FCIs as attributive indefinites, i.e. as modal indefinites requiring interpretation with respect to i(dentity)-alternatives. From this semantics the limited distribution of FCIs is derived: no i-alternatives can be invoked in episodic contexts. I conclude with some discussion of FCIs in Spanish and Catalan.

2 Two PI-paradigms in Greek: affective and free choice

Like Romance languages, and unlike English, Greek employs two morphologically distinct paradigms of affective PIs (roughly understood as related to negative polaity) and FCIs. The API paradigm is exemplified in (4):

(4)	kanenas	"anyone, anybody"
	tipota	"anything"
	pote	"ever"
	katholu	"at all"

APIs are licensed by nonveridicality, they are thus admitted in nonveridical contexts: negation, interrogatives, the protasis of conditionals, the scope of modal verbs and particles, subjunctive complements of strong intesional verbs, imperatives, disjunctions, and habitual (but not generic) sentences. Space prevents me from elaborating on the nonveridical character of these contexts (but see Giannakidou 1994, 1995, 1997 for details; also Zwarts 1995). FCIs are illustrated in (5), where *absolutely*-modification is intented to give the equivalence with free choice *any*:

(5)	opjosdhipote	" (absolutely) anyone, anybody"
	otidhipote	" (absolutely) anything"
	opotedhipote	"any time, whenever"
	opudhipote	"any place, wherever"

Morphologically, FCIs can be decomposed into three parts: *opjos* "free-relative who" (distinct from the interrogative and headed relative wh-), *dhi* "indeed" (emphatic particle from Ancient Greek), and *pote* "ever"(cf. English *whatsoever*). I argue below that the presence of *-dhipote* is important for the semantics. The distribution of FCIs parallels that of APIs in conditionals, modals and imperatives, *inter alia*, but unlike APIs, FCIs are also grammatical in DP-comparatives and generic sentences. Some examples are given below (for the complete distribution see Giannakidou 1997):

(6) Opjosdhipote bori na lisi afto to provlima. [modal]
anyone can.3sg subj solve.3sg this the problem
Anyone can solve this problem.

(7) Pare opjodhipote milo. [imperative]
take.2sg any apple
Take any apple.

(8) I Ilectra trexi grigorotera apo opjondhipote stin taksi tis. [DP-comp.]

the Electra run.3sg faster than anybody in-the class hers
Electra runs faster than anybody in her class.

(9) Opjadhipote ghata kinigai pondikia. [generic]
any cat hunt.3sg mice
Any cat hunts mice.

Two observations are in order: (a) FCIs show quantificational variability: sometimes they are understood with existential force ((7)) sometimes with universal (the rest). (b) Utterances with FCIs are generally better with rich descriptive content. Both facts will be shown to derive from the semantics I will present below. Crucially, FCIs are ungrammatical in affirmative episodic sentences and in typical API-environments: negation and interrogatives, as we see immediately below. Table 1 summarizes the contrastive distribution:

(10) * Idha opjondhipote ston kipo. [affirmative episodic]
saw.1sg anybody in-the garden
(* I saw anybody in the yard.)

(11) * I Roxani dhen idhe otidhipote. [negation]
the Roxanne not saw.3sg anything
(Roxanne didn't see anything.)

(12) * Agorases opjodhipote vivlio? [question]
bought.2sg any book
(Did you buy any books?/ *almost/absolutely any books?)

Table 1: (Partial) Contrastive distribution of APIs and FCIs in Greek

Environments	*APIs*	*FCIs*
Negation	OK	*
Polar/constituent questions	OK	*
Conditionals	OK	OK
modals	OK	OK
S-comparatives	OK	OK
Future particle	OK	OK
Subjunctives	OK	OK
Imperatives	OK	OK
Habituals	OK	OK
Generics	*	OK
DP-comparatives	*	OK

The facts suggest that FCIs and APIs do not exemplify the same kind of dependency. FCIs are admitted in arguably veridical contexts (generics and DP-comparatives; cf. Giannakidou 1995), and are excluded from non-veridical: negation and interrogatives (and others, which for reasons of space must be ignored here). Furthermore, the grammatical contexts for FCIs do not seem to form a natural class in terms of some semantic property, a point which becomes clearer if we consider the full set of data (cf. Giannakidou 1997). Finally, it is impossible to collapse the distribution, and thus the sensitivity of FCIs with that of English *any* (note, however, the ungrammaticality of *almost/absolutely* modification in the interrogative (12)).

3 Linking sensitivity to limited distribution: attributiveness and episodicity

In this section I provide an account of the distribution of FCIs by appealing to the semantics of these items. The idea I will pursue is this. Intuitively, free choice requires variation (cf. Kadmon & Landman's 1993 *widening*, Horn & Lee 1994, Dayal 1995, 1997, Tovena & Jayez 1997). The requirement on variation is encoded in the semantics of FCIs via their morphology. Recall the presence of *-dhipote* "indeed ever"in Greek FCIs ; modal marking is present in other languages, e.g. Hindi (Dayal 1995), Spanish (Bosque 1996) and Catalan). FCIs are then expected to occur in environments where the variation requirement is satisfied.

I propose to capture the variation requirement in terms of attributiveness by arguing that FCIs are attributive indefinites (for the distinction referential versus attributive see Donnellan 1966). Attributive indefinites are just like regular indefinites vis-a-vis their quantificational force, but, additionally, they admit paraphrases by like *whoever/whatever/etc that is,* indicating inability to identify reference. Quantificational variability of FCIs is to be expected under the assumption that they are indefinites. The need for rich descriptive content, on the other hand, comes from attributiveness: in attributive expressions the link between description and referent is essential.

Attributiveness is encoded as a modal feature on FCIs in the form of *-dhipote* "ever". The presence of this feature requires that FCIs be interpreted with respect to a set of alternatives to the world of evaluation w_0, what Dayal 1997 calls i(dentity)-alternatives (see also Farkas 1985). (13) illustrates what it means for a world to be an i-alternative:

(13) *i-alternatives* (a modified version of Dayal 1997)
A world $w' \in M_E(s)$ is an i-alternative wrt *x* iff there exists some $w'' \in M_E(s)$ such that $[[x]]_{w'} \neq [[x]]_{w''}$

Two i-alternatives w' and w" are worlds agreeing on everything but the value assigned to the FCI. $M_E(s)$ is a set of worlds representing the epistemic status of an individual (as I proposed in Giannakidou 1997) - in the default case of unembedded sentences the speaker's. Hence, i-alternatives are epistemic alternatives relative to an individual. In this context, FCIs denote existential quantifiers, just like regular indefinites (cf. (15)), which, however, must be evaluated against a set of i-alternatives as indicated by i-indexation in (14):

(14) $[[\text{opjodhipote vivlio}]]_{w0} = \lambda P\, [\forall \text{i-alt.} \in M_E(s)\, \exists x_i\, \text{book}(x_i) \wedge P(x_i)]$
(15) $[[\text{a book}]]_{w0} = \lambda P\, [\exists x\, \text{book}(x) \wedge P(x)]$

I illustrate how this proposal works with two examples. Consider (8) first, with a FCIs in a comparative. Given standard assumptions about comparatives as relations between individual and degrees mediated by maximality, this sentence's meaning is as in (16). The FCI, on the other hand, denotes the set indicated by (17):

(16) $\exists d\, [\text{fast}(d) \wedge \text{run}(E,d) \wedge d > \max(\lambda d'\, (\text{run}(\text{anyone in her class}, d')))]$
(17) $[[\text{opjondhipote stin taksi tis}]]_{w0} = \lambda P\, [\forall \text{i-alt.} \in M_E(s)\, \exists x_i\, \text{person-in-class-of-E}(x_i) \wedge P(x_i)]$

Consider now the i-alternatives in (18) and an ordering of degrees d' < d" < d"', such that the degree d' to which Roxanne runs is smaller than the degree d" to which Cleo runs and this, in turn, is smaller than the degree d"' to which Theodora runs:

(18) a i-alt_1: person-in-class-of-Electra (x_1) = Roxanne
$\exists d'\, [\text{fast}(d') \wedge \text{run}(\text{Roxanne}, d')]$

b i-alt$_2$: person-in-class-of-Electra (x_2) = Cleo
$\exists d'' [fast (d'') \wedge run (Cleo, d'')]$
c i-alt$_3$: person-in-class-of-Electra (x_3) = Theodora
$\exists d''' [fast (d''') \wedge run (Theodora, d''')]$

(16), then, says that Electra's degree of running is greater than the maximal degree to be associated with an individual considered in the i-alternatives, that is, Electra runs faster than even Theodora. The universal interpretation of the FCI is thus illusive: is not inherent to the FCI itself, but rather, it is due to the maximality operator. The same can be said about the universal-like flavor of (9) in the presence of the generic operator. In the absence of an operator inducing universal-like effects, the FCI is interpreted as a regular existential quantifier. To see this, consider occurrences of FCIs in imperatives as in (7)), evaluated wrt the set of i-alternatives in (19):

(19) a i-alt$_1$: apple (x_1) = apple$_1$
IMP [take (you, apple$_1$)]
b i-alt$_2$: apple (x_2) = apple$_2$
IMP [take (you, apple$_2$)]
c i-alt$_3$: apple (x_3) = apple$_3$
IMP [take (you, apple$_3$)]

Sentence (7) *Pare opjodhipote milo* "Take any apple" is an invitation to take some apple, be it apple$_1$, apple$_2$, or apple$_3$, and not all of them.

How does evaluation wrt to i-alternatives rule out FCIs from affirmative episodic, negative and interrogative sentences? The common feature of these sentences is that they are episodic, i.e. their logical representation involves existential closure of an event variable *e* (cf. Davidson 1967, Parsons 1990, Kratzer 1995), as is shown below for (10)-(12):

(10') $\exists e [\exists x (person (x, e) \wedge saw (I, x, e)) \wedge in\text{-}the\text{-}yard (e)]$ [aff.episodic]
(11') $\neg\exists e [\exists x\ thing (x, e) \wedge saw (Roxanne, x, e)]$ [negation]
(12') $Q\ \exists e [\exists x\ book (x, e) \wedge bought (you, x, e)]$ [interrogative]

Hence the ungrammatical cases form a natural class in terms of event closure. Episodicity in this sense will always block the possibility of invoking i-alternatives in virtue of its presupposing reference for the arguments of the event. In accordance with this analysis, FCIs turn out to be acceptable with individual-level predicates (and with generics, as we saw), where *e* is assumed to be bound inherently by GEN as in Chierchia 1995, or absent altogether as in Kratzer 1995:

(20) I Ilektra gnorizi opjondipote sto tmima.
the Elecrta knows anyone in-the department
Electra knows anybody in the department.
(21) $[[know]] = \lambda x_1\ \lambda x_2\ GENs\ (in'(x_1,x_2,s))\ [know'(x_1,x_2,s)]$(Chierchia 1995)

Hence, the proposed analysis of FCIs as attributive indefinites derives their restricted distribution in a simple way: attributive indefinites must avoid episodic domains. This is stated in the anti-licensing condition in (22):

(22) A free choice item *a* will not be licensed in a sentence S if S is episodic. Otherwise, it is licensed.

(22) predicts the right distribution not only for Greek FCIs but also for their Spanish and Catalan counterparts: *cualquier* "anybody"(Spanish), *qualsevol* "anybody" (Catalan). Space prevents me from going into this here, but see Bosque 1996 for a detailed exhibition of the relevant data. Suffice it to point

out that, like Greek FCIs, Spanish/Catalan FCIs also bear attributive marking: *-quier,* and *-sevol*, both corresponding to the intensional verb "want". Note, finally, that (22) is not proposed as a well-formedness condition on *any*, since the distribution of this item is quite different from that of FCIs. It seems plausible to treat *any* as a PI comprising FC- with nonveridical dependency, but I cannot but remain speculative at this point.

4 Conclusion

The major conclusions of the preceding discussion can be summarized as follows. First, FCIs were shown to be PIs distinct from APIs. Second, FCIs were analyzed as attributive indefinites which must be evaluated wrt a set of i-alternatives. This semantics enabled us to account for the exclusion of FCIs in episodic contexts: these are incompatible with attributive interpretations. As regards the greater PI-picture, the advantage of the proposed analysis lies precisely here: it links sensitivity to limited distribution, a connection which was seriously overlooked in the earlier approaches in the PI- literature.

Acknowledgment

I wish to thank Bill Ladusaw, Jason Merchant, and Josep Quer for particularly helpful discussion and comments.

References

Bosque, Ignacio. 1996. La polaridad modal. Ms. University of Madrid.

Chierchia, Gennaro. 1995. Individual-level predicates as inherent generics. In the *Generic Book.* Chicago University Press.

Dayal, Veneeta. 1995. Licensing *any* in non-negative/non-modal contexts. In SALT V. Cornell University, Ithaca, NY.

Dayal, Veneeta. 1997. Free relatives and *ever:* identity and free choice readings. To appear in SALT VII.

Davidson, Donald. The logical form of action sentences. In *The logic of Decision and Action.* ed. by N. Rescher, Pittsburg: University of Pittsburg Press.

Donnellan, Keith. 1966. Reference and definite descriptions. *The Philosophical Review* LXXV:281-304.

Farkas, Donka. 1985. *Intensional Descriptions and the Romance Subjunctive Mood.* PhD thesis, U. of Chicago. Publshed by Garland.

Giannakidou, Anastasia. 1994. The semantic licensing of negative polarity items and the Modern Greek subjunctive. *Language and Cognition* 4: 136-151.

Giannakidou, Anastasia. 1995. Subjunctive, habituality and negative polarity. In SALT V: 132-150. Cornell University, Ithaca, NY.

Giannakidou, Anastasia. 1997. *The Landscape of Polarity Items.*PhD thesis. University of Groningen.

Horn, Larry & Yung-Suk Lee. 1994. *Any* as an indefinite plus *even.* Ms. Yale University.

Kratzer, Angelika. 1995. Stage-level and individual-level predicates. In *The Generic Book,* ed. by G. Carlson and F.J. Pelletier. Chicago University Press:125-176. Also appeared as Kratzer 1988.

Ladusaw, William A. 1979. *Polarity Sensitivity as Inherent Scope Relations.* PhD thesis. UT Austin.

Parsons, Terence. 1990. *Events in the Semantics of English.* MIT Press.

Progovac, Liljiana. 1994. *Positive and Negative Polarity.* Cambridge University Press.

Tovena, Lucia and Jacques Jayez. 1997. The modal arbitrariness of *any.* Ms. University of Geneva and EHESS, Paris.

Zwarts, Frans. 1995. Nonveridical contexts. Linguistic Analysis 25, 3-4: 286-312.

On Some Semantic Consequences of Turn Taking[1]

Jonathan Ginzburg
Hebrew University of Jerusalem

Abstract

Implicit in most formal semantic work is the assumption that in a conversation the participants have equal access to the (semantic) objects in the context. In this paper I argue against this assumption by pointing out a puzzle concerning the resolution options in dialogue of fact-operator ellipsis. I develop an account of the puzzle within a dialogue-games approach by refining the structure on the common ground facts and explicating the update potential of utterances.

1 Introduction

Although it is generally accepted that conversational participants (CP's) play different roles at a given point in a conversation (e.g. querier v. responder), this is usually assumed to be a fact pertaining to the domain of speech act theory, not semantic theory. Implicit in this view is the following assumption, influential particularly since the dynamic approach to assertion and presupposition initiated by Stalnaker 1978: Equal Access to Context: *As a conversation proceeds a common ground emerges: A has her turn, reaches a transition relevance point(TRP); Then either A proceeds or B takes over* **from the common ground point at which A spoke.** In this paper I argue against Equal Access by pointing out a puzzle ('the Turn Taking Puzzle') concerning the resolution options in fact-operator ellipsis, which I suggest are crucially linked to the issue of who keeps or takes over the turn. I suggest that an account of the puzzle can be provided within a dialogue-games approach (see e.g. Hamblin 1970, Carlson 1983, Houghton and Isard 1987, Ginzburg 1995b, Roberts 1996). Specifically, a solution requires an extension of the approach in two directions: first, I motivate a two sorted structure for facts, thereby offering a dialogical and purely semantic version of the Right Frontier Constraint familiar from work on text structure; second, I offer an account of utterance acts from which emerges a fundamental speaker/addressee contextual asymmetry.

(1) and (2) exemplify the Turn Taking Puzzle. The data at issue here concern the resolution of the bare factive–operator wh-phrase 'why'. In examples like (1) two types of resolutions are, in principle available: one where the argument of the operator is the fact associated with the initial assertion ('the fact that B is upset'), the other where the argument is the fact characterizing the initial utterance ('the fact that A asserted that B is upset'). (1a), where at the TRP the original speaker keeps the turn, contrasts minimally with (1b), where two distinct speakers are involved. (2) is variant of (1) where the initial utterance is a query: in (2a), 'why' must pick up on a fact that positively resolves the initial question A poses, whereas when 'why' is uttered by a new speaker the resolution is to a fact characterizing A's initial utterance.[2] Notice that these data cannot be explained merely as a

[1] Earlier versions of this work were presented at the Israel Semantics Circle in Tel Aviv in January 1996, and at MunDial 97 in Munich. Thanks to the participants for helpful comments and interaction, in particular to Nicholas Asher, Fred Landman, Massimo Poesio, Susan Rothstein, and Henk Zeevat. This paper summarizes chapters 4, 6, and 8 from a forthcoming book tentatively titled *Interaction in Dialogue: a Semantics* . All are available by ftp from ftp.cogsci.ed.ac.uk:pub/ginzburg

Thanks to an Alon fellowship for financial support.

[2] Similar mismatches arise with other factive wh-operators such as 'where', 'when', 'how' etc, as illustrated in (i) and (ii):

(i) A: who attacked you? (and) where? [roughly: where did *that person* attack you?]

(ii) A: who attacked you? B: where? [roughly: what place l are you asking who attacked me at l?] 'why' does exhibit certain idiosyncracies discussed in the full version of this paper.

consequence of the differing coherence of an utterance depending on who makes the utterance: the resolution unavailable to A in (1a)/(2a) *is* coherent when it arises from a non-elliptical utterance, as in (1c)/(2c). Rather, what this data seems to show is that **which semantic objects are available to a particular dialogue participant, i.e. which entities she can exploit in elliptical or anaphoric resolution, depends in part on the role that participant has most recently played in the conversation.**

(1a) A: You're upset. Why? (unambiguously: 'Why is B upset?')
(1b) A: You're upset. B: Why? (strong preference: 'Why does A claim B is upset?'; 'why is B upset?' weakly available)
(1c) A: You're upset. Why do I say that?

(2a) A: Where was your Grandmother's sister born? Why? (Unambiguously: 'Why was she born *there*?')
(2b) A: Where was your Grandmother's sister born? B: Why? ('Why do you ask where she was born?')
(2c) A: Where was your Grandmother's sister born? (and) Why am I asking this question?

2 Semantics for Dialogue

The Turn Taking Puzzle (TTP) appears to constitute a direct refutation of Equal Access. In order to develop a solution I adopt the perspective of dialogue-games frameworks (refs above): this allows one to view conversation as a game the rules for which can affect distinct participants differently at a given point. In fact, the TTP also argues against dialogue game formulations stated exclusively as operations on a common ground, as e.g. in Roberts 1996, precisely because such formulations implicitly assume that Equal Access obtains. In attempting to defuse the tension between individual and common aspects of "context", I adopt the following strategy: the basic domain of description is taken to be the mental state, avoiding a regress into solipsism by positing that conversational rules involve updates by each CP of her own *dialogue-gameboard* (DGB), a quasi-public informational repository (cf. Hamblin's *individual commitment slate*).
As a starting point I take the view of DGB structure and updates articulated in Ginzburg 1994, 1995b, 1997a: on this view the DGB is structured by at least the following attributes:[3] **FACTS**: a set of facts, closed (cf. Asher 1993) under meets and joins; **QUD**('questions under discussion') : a set consisting of the currently discussable questions, partially ordered by $\prec$ ('takes conversational precedence'). Both querying and assertion involve a question becoming maximal in the querier/asserter's QUD, the posed question q for a query q, p? for an assertion p. Roughly: the responder can subsequently either choose to start a discussion (providing information σ that is ABOUT q/p? or posing a question q_1 on which q/p? DEPEND) or, in the case of assertion, update her FACTS structure. A CP can downdate q/p? from QUD when, as far as her (not necessarily public) goals dictate, sufficient information has been accumulated in FACTS.

3 FACTS and its Structure

3.1 The locality of fact ellipsis

The first extension a framework like that of Ginzburg 1995b, 1997a requires in order to account for the TTP, I suggest, is the imposition of a bi-sortal structure on

[3] I have also argued in the afore-mentioned works that the DGB keeps track of an attribute dubbed 'LATEST-MOVE', representing information about the content and structure of the most recent accepted illocutionary move. In the current, concise exposition, I will ignore this rather crucial attribute.

FACTS. One motivation for this is the strictly local nature of fact-entity ellipsis and anaphora. Consider (3a): in (iv) 'why' has two possible resolutions, as indicated below. However, if this dialogue continues from (iii) with the turns (iv')-(vi'), the resolution possibilities change, in particular the facts previously available as resolutions are no longer available:

(3a) A: Who's left recently? B(iii): Bill. A: Is he the guy everybody hates? B(iii): Yeah. A(iv): Hmm. Do you know why? (why: why Bill left recently. or: why does everybody hate Bill.)

(3b) A(iv'): Uh huh. B(v'): Mary also left. A(vi'): Hmm. So, do you know why? (**why:** why Mary left recently. or: why Mary left recently and Bill left recently. **not:** why does everybody hate Bill, why Bill left recently.)

Now although such dialogue data have not, to the best of my knowledge, been addressed before, they seem clearly analogous to the phenomena addressed by work on fact and propositional anaphora in texts. Both Webber 1991 and Asher 1993 have proposed accounts based on a tree-configurational view of discourse structure primarily constrained by the Right Frontier Constraint(RFC) (Polanyi 1987). Given certain fundamental differences between text and dialogue, as discussed in Ginzburg 1997b, one cannot take over directly these text-theoretic notions. Below I sketch the purely semantic, dialogical version of the RFC from Ginzburg 1997b, based on an analogy that relates the text-derived notion of *open constituent* ("unexhausted topic") with the dialogue–derived notion of *question (currently) under discussion.*

3.2 Hasty Accommodation

An additional motivation for the bi-sortality of FACTS concerns what one might term *hasty accommodation*: although at the best of times information is taken to be *presupposed* only once all CP's have indicated that they accept it, a speaker can, nonetheless, coherently presuppose material that has not been accepted into the DGB and after discussion retract it:

(4) A: Merle Frankenstern hasn't published much recently. That (fact) disappoints me. B: No, she's just published a couple of books over the past year. A: Oh really.

A related phenomenon is illustrated in (5), similar to (1a) and (2a), where two questions are posed by a single speaker. Apparently, the only possible resolutions are the corresponding resolutions in (6), *not* the corresponding parenthesised resolutions:

(5a) A: Who left the institute before 5? (and) Why?
(5b) A: Did Bill buy that book for Mary? At what time?
(5c) A: Is Millie going to get a job? Why?

(6a) Why did they, those people that left the institute before 5, leave? (Why did no one leave the institute before 5?)
(6b) At what time did Bill buy that book for Mary? (At what time did Bill not buy that book for Mary?)
(6c) Why is Mary going to get a job? (Why is Mary not going to get a job?)

Thus, what is accommodated are the *positive* resolutions to the question, *not* just any resolving SOA. That is, we have what seems to be a conventionalized accommodation strategy, since as far as plausibility goes, nothing should rule out the negative resolutions.[4] However, nothing guarantees that the positive resolutions are factual, so just as in (4) they might need retracting.

[4]See Ginzburg 1995a for arguments against associating an existential *presupposition* with a wh-interrogative, based in particular on the existence of contexts where a querier not only *lacks* the requisite presupposition but actually suspects that it is false and yet can, entirely felicitously, pose a wh-question. Note that, nonetheless, even in such contexts, e.g. in (i), even if A suspects strongly that no one contacted the police, it does not seem that the second conjunct can come to mean (ii):
(i) A: Who contacted the police and why?
(ii) why did no one contact the police?

3.3 Two grades of Facts

The phenomena discussed in the previous sections lead me to the following conclusion: in addition to the standard structure on FACTS, one needs to recognize a *localized*, "temporary" component of FACTS, so that liable to be corrected material is *not* fully integrated into the DGB using $+_{facts-closure}$ (unioning in of the SOA plus closure under $\vee/\wedge$) *before* discussion, since retraction will be costly. Thus, one needs to recognize two grades of SOA's within DGB | FACTS. The first sort of element in FACTS are SOA's dubbed STORED.[5] Such SOA's are to be thought of as items of information that truly have the acceptance of all conversational participants, following perhaps some discussion. They can thus be safely integrated with the conversationally emergent body of knowledge: STORED will be closed under $\vee$ and $\wedge$. The second sort in FACTS, to be dubbed TOPICAL, concerns SOA's that pertain to questions under discussion at that point in time. TOPICAL will be treated as a set of pairs of $a = \langle$ question$_0$,soa$_0$ $\rangle$, where question$_0$ (a's *address*) is an element of QUD, soa$_0$ is ABOUT q_0. TOPICAL is updated using *priority union* (Carpenter 1993, Grover et al 1994), a defeasible update operation in which later accepted material takes precedence, hence allowing for an account of hasty accommodation.

As far as querying and assertion: in this revised setup updating QUD has the additional consequence of introducing a new ADDRESS in TOPICAL about which SOA's can be provided, together initially with the trivial SOA $\top$. In addition, when a new question gets introduced, the addresses for questions that are no longer under discussion are downdated from TOPICAL. This latter assumption represents our own version of the RFC. Consequently: the hypothesis I make is that:

It is precisely the SOA's in FACTS | TOPICAL to whom access by ellipsis and pronominal anaphora is possible.

For reasons of space I restrict myself to illustrating the account by considering a simple example, as given in (7), which abstracts away ¿from various details irrelevant for current concerns, concentrating mainly on the evolution of TOPICAL. The dialogue works essentially as follows: A asks a question in (i), q_1, to which B responds in (ii). A accepts the assertion in (iii). Let us assume she is now ready to move on to another issue, the one she raises in (4), so she can now downdate from QUD both q_1 and the question 'Bill left recently?'. At this point there is one possible fact antecedent in TOPICAL, 'Bill left recently'. This can, therefore, serve as an antecedent for A's 'why' in (iv). However, a side effect of A's posing her question in (iv) is that the addresses corresponding to q_1 and to 'Bill left recently?' get downdated from TOPICAL, since these questions are no longer in QUD, therefore *inter alia* eliminating 'Bill left recently' as a possible elliptical fact antecedent. Notice that there is, thus, always a one move lag between the downdating of questions from QUD and the disappearance of the addresses they provide in TOPICAL. This seems like an intuitive prediction: once some information is no longer contentious, one still wants to be able to use it as a constituent of other contents which "comment" on it.

(7) (i) A: Who's left recently? FACTS | TOPICAL: $\langle q_1, \top\rangle$
(ii) B: Bill. FACTS | TOPICAL: $\langle q_1, \top\rangle$, $\langle$ 'Bill left recently?',$\top\rangle$
(iii) A: Uh huh.
FACTS | TOPICAL: $\langle q_1$, 'Bill left recently' $\rangle$, $\langle$ 'Bill left recently?','Bill left recently' $\rangle$
Downdates 'Bill left recently?', q_1 from QUD: QUD:= $\emptyset$
(iv) A: Why? FACTS | TOPICAL:= $\langle q_2, \top\rangle$

[5] One can, speculatively, think of this distinction as relating to a long-term memory v. working memory distinction.

4 Utterances and Updates

As commonly conceived formal semantic approaches bypass entirely issues pertaining to communication. However, for dialogue such a strategy is untenable given that a large proportion of the utterances directly concern the conversation itself—whether an utterance has been understood, if not what aspects need clarifying etc. To take a concrete example, (1b) and (2b) cannot be analyzed without allowing facts and questions that concern A's previous utterance enter the DGB in some way. The view of communication developed in Ginzburg 1997c starts out from the commonplace observation that A being the speaker and B the addressee involves a basic asymmetry in their roles, but takes this to what might seem at first like a rather surprising conclusion. The asymmetry between speaker and addressee is that whereas it is *incoherent* for A to make an utterance u without being aware of the content he intends to convey, the content of u is not automatically transparent to the addressee B, who must continually signal whether or not (she believes) she understands what u meant (for psycholinguistic evidence concerning this "grounding" process see Clark 1996). The view of utterance update I develop leads to a significant mismatch between the updates A and B perform on their respective DGB's as a consequence of A's utterance.

Simplifying significantly, for obvious reasons of space, the basic idea is this: when B forms the belief that A has made an utterance u whose conventional meaning is μ, the first issue she is obliged to contend with, obliged by virtue of participating in the conversation, is *what did A intend to convey with u whose meaning is* μ*?* Concretely, I take this to involve introducing into QUD two questions: the (conventional) content question [content(u,μ)?] and the goals question [goals(u,A)?]. Roughly: content(u,μ)? is the question individuated by u and μ, the abstract corresponding to the (Kaplan/Barwise-Perry view of) sentential meaning used in u ('what values do the contextual parameters of μ get in u');[6] goals(u,A)? is the question 'what goals did A have in making u'. It is only if B believes she knows the answers to both content(u,μ)? and goals(u,A)?, that she can proceed to update her DGB, downdating both these questions from QUD and acting in accordance with the illocutionary act that has taken place; otherwise a clarification stage must ensue. An important consequence of this update process on B's DGB is that certain facts relating to the utterance itself become TOPICAL, specifically those facts that pertain to content(u,μ)? and goals(u,A)?.[7] Such facts, nonetheless, lose their TOPICALness very quickly due to their addresses being downdated from QUD, assuming that understanding has been attained, in a way analogous to that illustrated in section 3.3.

Crucially, I argue that as a rule neither content(u,μ)? nor ¿goals(u,A)? get added to *A's QUD* as a consequence of A's utterance—A makes her utterance without any explicit wish or need to address these questions. I suggest that there is here a disanalogy with assertion, where I assume that, in general, both asserter and her addressee *do* have the issue p? in QUD as a consequence of an assertion p: when an assertion p is made, the asserter is committed to a belief p, but has no guarantee that p will be accepted by her interlocuter; only some usually well founded hope that the interlocuter will address the issue *whether p*. With an utterance, however, as a rule, the utterer A *does* know what she has just said and meant and can assume that B will (perhaps immediately, perhaps eventually) know it too. Thus, the strategy I will

[6] The actual account I develop makes use of more structured objects than sentential meanings of this kind, motivated in part by the need to account for phrasal ellipsis clarification possibilities.

[7] That a fact pertaining to content(u,μ)? becomes TOPICAL has been exemplified in (1b) and (2b) above; (i) is an analogous example for goals(u,A)?:

(i) [Context: B has annoyed A] A: OK, well bye! B: But why? (= Why are you indicating you're leaving?)

propose is similar in spirit to the one proposed in Ginzburg 1997b with respect to query acceptance: there I argued that one of the DGB update operations performed by the querier, A, is to add q to his DGB, despite the possibility that the responder, B, will not adopt q. It was left *as an option for B* to raise the issue of *whether q was to be discussed.* Similarly here, I suggest that in general A herself has no explicit intention to discuss either content(u,μ)? or goals(u,A)? —as far as her own DGB goes she need not adopt these as issues in QUD unless B provides indications to the contrary.

5 Accounting for the TTP

I conclude by sketching an account of the TTP, discussing here the data in (2). The reading A can get in (2a) is possible since, by the accommodation strategy mentioned in section 3.2, after A's initial query the question q_0 = 'where B's grandmother was born' is QUD-maximal, so A can accommodate a positive resolution of q_0 into her FACTS | TOPICAL—this gives her the requisite fact. On the other hand, since content(u,μ)? never gets into A's QUD, a fact positively resolving content(u,μ)? is not TOPICAL, so is not accessible to A. B's options: a fact positively resolving content(u,μ)? *is* TOPICAL for B immediately after A's utterance, so is accessible to B. Why does the resolution in (2a) not arise? *Before* B grounds A's utterance, the posed question q_0 it is not in B's QUD. Hence, accommodating a fact positively resolving q, pos-res(q), is not possible. *After* grounding there are a two options: (a) If an answer is provided, this answer will subsume the fact that is pos-res(q) [see (8b)]. So the pos-res(q) reading disappears. (b) If no answer is provided, the pos-res(q) reading remains as an option, shown in (8c):

(8a) A: Who solved the chess problem? / (8b) B: Gary and Judit. I know how too. / (8c) B: I'm not quite sure. I do know how though.

6 References

Asher, N. 1993, *Reference to Abstract Objects in English*, Kluwer: Dordrecht.

Carlson, L. 1983, *Dialogue Games*, Reidel: Dordrecht.

Carpenter R. 1993 'Skeptical and credulous default unification with applications to templates and inheritance'. In: T. Briscoe, A. Copestake, V. de Paiva (eds.) *Inheritance, Defaults, and the Lexicon*, Cambridge University Press: Cambridge.

Clark, H. 1996 *Using Language*, Cambridge University Press: Cambridge.

Ginzburg, J. 1994, 'An Update Semantics for Dialogue'. In: H. Bunt, R. Muskens, G. Rentier (eds.) Proceedings of the International Workshop on Computational Semantics, ITK: Tilburg.

Ginzburg, J. 1995a, 'Resolving Questions, I', *Linguistics and Philosophy*, 18: 459–527.

Ginzburg, J. 1995b'The Semantics of Interrogatives', In: S. Lappin (ed.) *Handbook of Contemporary Semantic Theory* , Blackwell: Oxford

Ginzburg, J. 1997a, 'Querying and Assertion in Dialogue, I', Hebrew University of Jerusalem Ms.

Ginzburg, J. 1997b, 'Querying and Assertion in Dialogue, II: defeasible presuppositions, fact ellipsis, and non-cooperativity', Hebrew University of Jerusalem Ms.

Ginzburg, J. 1997c, 'Uttering in Dialogue: a protocol', Hebrew University of Jerusalem Ms.

Grover, C. and C. Brew and S. Manandhar and M. Moens and A. Schoter 1994, 'Priority Union and Generalization in Discourse Grammar', In: A. Schöter and C. Vogel (eds.) *Edinburgh Working Papers in Cognitive Science: Nonclassical feature systems*, Centre for Cognitive Science, University of Edinburgh.

Hamblin, C.L. 1970, *Fallacies*, Methuen: London.

Houghton G. and S. Isard 1987 'Why to speak, what to say and how to say it: modelling language production in discourse', In: P. Morris (ed.) *Modelling Cognition*, Wiley: London, p. 249–267.

Polanyi, L 'A formal model of the structure of discourse', *Journal of Pragmatics*, 12:601-638.

Roberts, C. 1996 'Information Structure in Discourse', Ohio State Working Papers in Semantics, Ohio State University, Columbus

Stalnaker, R. 1978 'Assertion'. In *Syntax and Semantics 11.*

Webber, B. 1991 'Structure and Ostension in the Interpretation of Discourse Deixis', *Language and Cognitive Processes* 6: 107–135.

A Discourse Account of Argument Containment Effects

Daniel Hardt
Villanova University/Center for Sprogteknologi
Nicholas Asher
University of Texas at Austin

1 Introduction – The ACE Generalization

It has been observed by Kennedy (94) that ellipsis in argument containment configurations gives rise to a constraint that requires identity of parallel arguments. While both Kennedy and Heim (97) have proposed accounts of these argument-contained ellipsis (ACE) effects, we show that similar effects arise in a variety of configurations that do not involve argument containment. We present an analysis in terms of Segmented Discourse Representation Theory (SDRT, Asher 93), in which VPE and antecedent are contained in separate constituents of a discourse structure that must participate in a felicitous discourse relation. This relation requires that the *backgrounds* of the containing discourse constituents be semantically related. ¿From this perspective, Kennedy's observations emerge as straightforward consequences of basic constraints on discourse relations, familiar from SDRT and many other theories.

Consider the following contrast:

(1)a. *Everyone who SAID George would leave DID.
b. Everyone who SAID he would leave DID.

As Kennedy observes, the example is only felicitous if the subject of the antecedent VP is identical to the subject of the VPE. Kennedy proposes an account of this in terms of argument containment, based on the following generalization:

> Ellipsis between VP_α and VP_β, VP_β contained in an argument A_α of VP_α, is licensed only if A_α is identical to the parallel argument A_β of VP_β.

This correctly captures the contrast in (1), because the antecedent VP *leave* is contained in the subject of the VPE. In (1b), the subject of the antecedent VP (*he*) is identical to the subject of the VPE *Everyone who said he would leave*, while in (1a), the subject of the antecedent VP (*George*) is not identical to the subject of the VPE. Heim (97) captures this contrast by means of the following two principles:

- the VPE must be contained in a constituent that "contrasts appropriately" with a constituent containing the antecedent (Rooth 92); more specifically, the *focus value* of the constituent containing the VPE must contain the semantic value of a constituent containing the antecedent.[1]
- VP's have the semantic type of formula rather than property. This has the effect of requiring that the minimal containing constituents are S's, rather than what are traditionally considered VP's.

Heim argues that this correctly captures the contrast in (1), since, in (1b), the constituent *DID x [leave]* containing the VPE contrasts appropriately with the constituent *x said x leave*. Intuitively, this is because the focus value of the VPE-containing constituent is that *x leave* has some property P, and the antecedent

[1] Focus value, as described in Rooth 92, is constructed from an ordinary semantic value by creating the set of objects with all possible substitutions for focused elements.

constituent applies the property *being wanted by x* to *x leave*. Appropriate contrast cannot be found for (1a). (See Heim 97 and Rooth 92 for details.)

2 Beyond Argument Containment

Next, we turn to examples that exhibit similar contrasts to that found in (1), but where there is no argument containment.[2]

(2)a. *They SAID George would leave and they DID.
b. They SAID they would leave and they DID.
(3)a. *Tom kissed everyone who ASKED Bill to.
b. Tom kissed everyone who ASKED him to. (Haik 87)
(4)a. *Every woman who SAID Mary would ask Bill to leave, ASKED him to.
b. Every woman who SAID she would ask Bill to leave, ASKED him to.

Since these examples do not involves argument containment, Kennedy's account does not apply. Heim does not explicitly consider examples like (2) and (3), and we will not explore whether her account would apply to these examples. However, (4) demonstrates a crucial difference between Heim's account and ours: as we discuss below, our account correctly captures the contrast, because it requires that the parallel relation be applied to *maximal* SDRS constituents containing the VPE and the antecedent, respectively. Heim's account fails to rule out (4)a, because it permits an appropriate contrast to be found between smaller constituents.

3 The Proposed Account

Our account consists of a requirement that VPE occur in felicitously-related discourse constituents, together with a simplified version of what constitutes such felicitous relations in SDRT. More specifically, we propose the following:

- **VPE Constraint:** VPE and antecedent must occur in a felicitously related pair of discourse constituents <K1, K2>, where K1 is a maximal SDRS constituent containing antecedent VP and not containing VPE, and K2 is a maximal SDRS containing the VPE and not containing the antecedent VP.
- **Discourse Relations:** a pair of Parallel discourse constituents is felicitous if their backgrounds are inferentially related. We permit a certain class of defeasible inferences in determining the inferential relation.
- **Defeasible Inferences:** we invoke defeasible inferences of this form:

  $\exists x.\ B(x,\phi) \rightsquigarrow P(\phi)$

  where B is a propositional attitude (*say, believe, etc*) and *P* is a propositional operator (*do, will, might, etc*), and ϕ is a proposition.

In this paper we will be restricting our attention to Parallel, which is the default discourse relation. In the presence of certain cues, other relations, such as Contrast, can be inferred. Backgrounds are constructed by replacing accented items with variables, which are implicitly existentially quantified.[3]

[2] It should be noted that (3) does involve object argument containment, but this is not relevant in this case, since the contrast involves the *subjects* of the VPE and antecedent, *Bill* and *Tom*.

[3] This is a simplified version of the Parallel discourse relation of SDRT and many other accounts of discourse relations. It is also closely related to Rooth's notion of alternative semantics. Note that we ignore the issue of "focus percolation", where some object larger than the accented constituent is abstracted over.

The defeasible inference schema is meant to cover any substitution of propositional attitude for B and propositional operator for P, for example, $\exists x$. SAY(x,leave(x)) $\rightsquigarrow$ DO(leave(x)). One special case is worthy of note, where B and P are existentially quantified

$\exists x, B.B(x,\phi) \rightsquigarrow \exists P.P(\phi))$

This pattern arises when the B and P represent accented elements, which are replaced with existentially quantified variables. We also permit inferences where there is no operator P. Note that the existentially quantified variables in instantiations of our schema are dynamically bound as is standard in DRT-style formalisms.

We take no position here on the mechanism by which the VPE is recovered; our account is broadly compatible with a variety of proposals in the literature (see Asher *et al* (97)) for one proposal and references to other compatible approaches).[4]

We now return to example (1), repeated here.

Example 1

(a) *Everyone who SAID George would leave DID.

(b) Everyone who SAID he would leave DID.

We construct the following DRS for (1a):

$[[u_1 \mid \text{SAID}(u_1,\text{leave}(\text{george}))] \Rightarrow [\ \mid \text{DID}(\text{leave}(u_1))]$

We abstract over accented constituents to produce the following pairs of backgrounds:

(a) $B(u_1,\text{leave}(\text{george}))$ $\quad P(\text{leave}(u_1))$
(b) $B(u_1,\text{leave}(u_1))$ $\quad P(\text{leave}(u_1))$

In (1b), the backgrounds are properly related by our defeasible inference schema, while in (1a), infelicity results because neither background is inferrable from the other. We now give the backgrounds for (2)-(4).

Example 2

(a) $B(u_1,\text{leave}(u_2))$ $\quad P(\text{leave}(u_1))$
(b) $B(u_1,\text{leave}(u_1))$ $\quad P(\text{leave}(u_1))$

Example 3

(a) $B(u_1,\text{kiss}(\text{bill},u_1))$ $\quad \text{kiss}(\text{tom},u_1)$
(b) $B(u_1,\text{kiss}(\text{tom},u_1))$ $\quad \text{kiss}(\text{tom},u_1)$

Example 4

(a) $B(u_1,\text{asked}(\text{mary},\text{leave}(\text{bill})))$ $\quad P(u_1,\text{leave}(\text{bill}))$
(b) $B(u_1,\text{asked}(u_1,\text{leave}(\text{bill})))$ $\quad P(u_1,\text{leave}(\text{bill}))$

In each of the (b) examples, the second background follows from the first background by the defeasible inference schema, while in the (a) examples, there is no inferential relation between the two backgrounds.

Note that Heim's account would incorrectly accept (4a). This is because "appropriate contrast" can be found between the constituent *Bill to leave* and *him to (leave)*. This illustrates a key difference between our account and Heim's: we require that comparison be made between maximal constituents containing VPE and antecedent, while Heim permits comparison of *any* pair of containing constituents.

[4]Note that we restrict attention to cases of ACE involving subjects. The following is an example of object-containment, from Kennedy (94):

(5) *Polly visited every town in every country Eric did.

In our view, this example should be ruled out by the VPE resolution mechanism; more precisely, a constraint on index change within the ellipsis site in the absence of parallel controllers. Many accounts of VPE resolution in the literature correctly make this prediction, such as Sag (76), Williams (77), Fiengo and May (94), among others. Thus, we set aside object-contained ACE cases in this paper.

4 Additional Data

We now examine further data that distinguishes our account from those of Heim and Kennedy. Consider the following example:

(6) *Everyone who said GEORGE did left.

This example is ruled out on our approach, just as example (1a) is ruled out. However, this example is accepted on Heim's account, because the alternative set of the VPE consists of propositions of the form *x left*, and the antecedent clause (the entire sentence) is an element of this set. We turn now to the following example, which is a variant of example (4):

(7)a. Every $woman_1$ who SAID she_1 would ask $Bill_3$ to help her_2, ASKED him to.

b. *Every $woman_1$ who SAID $Mary_2$ would ask $Bill_3$ to help her_2, ASKED him to.

On our account, (7)a is accepted via defeasible inference, since we have the following backgrounds:

$P(u_1,ask(u_1,help(bill,u_1)))$ $Q(u_1,help(bill,u_1))$

Example (7)b is rejected, because the following backgrounds are not inferentially related:

$P(u_1,ask(mary,help(bill,u_1)))$ $Q(u_1,help(bill,u_1))$

Heim's account will accept (7)b if the pronoun *her* receives a *strict* reading under VPE interpretation. [5] Under the strict reading, appropriate contrast can be found between the constituents "Bill to help her" and "him to help her". Under the sloppy reading, there is no way of finding appropriate contrast, regardless of the position of focus of the choice of containing constituent. While Heim's account accepts the strict reading and rejects the sloppy reading in (7)b, we find the example unacceptable on either reading.

5 Discussion: Defeasible Inference

The notion of defeasible inference plays a crucial role in our account, since it allows constituents to be felicitous with backgrounds that are not semantically identical, if they are related by a defeasible inference of the form $B(x,\phi) \leadsto P(\phi)$ where B is a propositional attitude and P is a propositional operator.[6] The rationale underlying these patterns is the following: when an agent takes possible state of affairs to be a real possibility (as in *they feared they would lose and they did*; *they wanted to win and they did*), to be actually the case (*they were certain they would win and they did*), or to be an intended course of action (*they said (promised, bet) they would*

[5]Despite the lack of argument containment, Kennedy's account makes the same prediction here as Heim's, because of Kennedy's requirement that the pronoun *her* be "co-bound" in both antecedent and ellipsis site. See Kennedy (94) for details.

[6]We have examined only inferences which in SDRT terms instantiate the discourse relation of Parallel. The proposed account applies in a similar way to examples involving Contrast, such as the following:

(8) Everyone who refused to leave in the end did.

(9) Everyone who said they would boycott the company in the end didn't.

(10) They promised they would not leave and yet they did.

In these examples one of the SDRS constituents contains a contrastive discourse particle ("in the end", "yet"). So in these cases we will infer Contrast between the constituents with the attendant effects on backgrounds. The patterns that we used in the Parallel cases above—$P(\phi) \leadsto B(\phi)$—when applied to these cases defeasibly imply the negation of constituent containing the VPE, which is what we require for Contrast.

win and they did), the agent typically has the sort of evidence that would lead any agent, including the reader, to expect that the state of affairs obtains. A wide range of attitude verbs express attitudes that give rise to such expectations—including all the positive intensional nonfactives of Asher (87) but also verbs like *fear*[7]. It has been crucial in our account that defeasible inferences are not invoked in patterns like the following: $B(x, \phi) \leadsto P(\psi)$. Clearly, there is no expectation of evidence for ψ, given x B's that ϕ. Thus the defeasible inference cannot be invoked.

5.1 Extending the Inference Schema

Consider now the following example (M. Steedman, p.c.):

(11) Every_1 woman who SAID she_1 would ask Bill_2 to leave, ORDERED him_2 to.

(12) ?*Every_1 woman who SAID Mary_3 would ask Bill_2 to leave, ORDERED him_2 to.

Here, our account predicts that (11) is felicitous, making use of a defeasible inference followed by an ordinary inference. (12) is infelicitous on our approach. Both Heim's and Kennedy would accept both examples, just as in example (4)b. We have the following backgrounds for (11):

$\text{P}(\text{u}_1,\text{ask}(\text{u}_1,\text{leave(bill)}))$ $\quad$ $\text{Q}(\text{u}_1,\text{leave(bill)})$

These two backgrounds are not precisely an instantiation of the defeasible inference schema. In this case, we require an additional, non-defeasible inference. We have

$\text{P}(\text{u}_1,\text{ask}(\text{u}_1,\text{leave(bill)})) \leadsto \text{ask}(\text{u}_1,\text{leave(bill)})$
$\text{ask}(\text{u}_1,\text{leave(bill)}) \leadsto \text{Q}(\text{u}_1,\text{leave(bill)})$

(Recall that abstraction variables like Q are existentially quantified.)

Consider now the following examples, all of which we find acceptable:

(13) A man who feels someone ELSE should do the dishes will often REFUSE to.

(14) Among computer science students, those_1 who UNDERSTAND that students_2 mustn't cheat, generally DON'T.

Note that (14) is ruled out by Kennedy's ACE generalization, on the (natural) reading in which $\textit{those}_1$ is not coreferential to $\textit{students}_2$. It also appears to us that Heim's account will incorrectly reject (13)-(14). These examples suggest an natural extension of our defeasible inference schema, along the lines of the following:

$\forall a.action(a) B(x, ought(x, a)) \leadsto do(x, a)$

"If someone believes he ought to do something, he does it."

With this extension, we suggest that our account would correctly accept the above examples, although space does not permit a detailed examination of this here.

6 Conclusion

We have claimed that Kennedy's observations about argument containment reflect basic constraints on parallelism in discourse. In particular, we require that VPE and antecedent occur in felicitously related discourse constituents. This follows the

[7]See Asher (87) for further discussion, including consideration of negative nonfactives, rogative, and buletic attitude verbs.

spirit of the Heim/Rooth claim that VPE interpretation requires appropriate contrast. However, we require a felicitous relation between maximal, non-overlapping structures containing VPE and antecedent. The maximality and non-overlapping requirements are not specific to VPE, but are quite general features of the application of discourse relations such as Parallel and Contrast. In SDRT, the maximality requirement follows from the Right Frontier Constraint on discourse attachment, which forbids asserting a relation between the currently constructed discourse constituent and a subpart of a previously constructed constituent. Nor can containing or overlapping constituents be related, since this would either violate the Right Frontier Constraint or lead to a non-wellfounded structure. Similarly, the maximality and non-overlapping requirements essentially emerge as a consequence of the derivation system of theme-rheme relations of Steedman (97). We have claimed that felicitously related discourse constituents have inferentially related backgrounds, and we have described a pattern of defeasible inference that plays a crucial role in determining felicity. We conjecture that defeasible inference schemas of this sort are also general features of the discourse interpretation process. Our account relies on very general properties of discourse interpretation; as a result of this, the account captures a variety of facts that are left unexplained by the Kennedy and Heim accounts.[8]

References

1. Asher, N. (1987) A Typology for Attitude Verbs and Their Anaphoric Properties, Linguistics and Philosophy, 10 (1987), pp. 125-198.
2. Asher, N. (1993) *Reference to Abstract Objects in English*, Dordrecht.
3. Asher, N., Hardt, D., and Busquets, J. (1997) Discourse Parallelism, Scope, and Ellipsis, in A. Lawson and E. Cho (Eds.), *Proceedings, SALT VII*, Cornell University, CLC Publications.
4. Haik, I. (1987) Bound VPs That Need to Be. Linguistics and Philosophy, 10 (1987), pp. 503-530.
5. Heim, I. (1997) Semantic Types for Syntactic Categories: Evidence from Ellipsis, in A. Lawson and E. Cho (Eds.), *Proceedings, SALT VII*, Cornell University, CLC Publications.
6. Kennedy, C. (1994) Argument Contained Ellipsis. Santa Cruz, Linguistics Research Center Report LRC-94-03.
7. Rooth, M. (1992) Ellipsis Redundancy and Reduction Redundancy, in S. Berman and A. Hestvik (Eds.), *Proceedings of the Stuttgart Ellipsis Workshop*, Stuttgart.
8. Steedman, M. (1997) Information Structure and the Syntax-Phonology Interface. Submitted, http://www.cis.upenn.edu/steedman/papers.html.

[8]Many thanks to Chris Kennedy and Mark Steedman for discussion and comments.

On the interpretation of semantic relations in the absence of syntactic structure
(extended abstract)

Petra Hendriks & Helen de Hoop (Groningen & Utrecht)

Summary
In order to yield the intended interpretation for quantified expressions and comparatives, a compositional interpretation based on syntactic structure alone is not always possible. In the interpretation of these expressions, contextual information plays an important role. In general, we argue that context allows for a set of possible interpretations of an expression. Syntax may reduce this set of interpretations to yield a specific interpretation.

Determiners

(1) Most boys were rejected because of their height

Intuitively, sentence (1) is true if and only if more boys are rejected because of their height than because of any other reason, implying that the domain of quantification (set A) is not supplied by the noun *boys* alone, but further restricted by the predicate *were rejected*. This interpretation for (1) can be reinforced by stressing *because of their height* (cf. Partee 1995, De Hoop & Solà 1996, De Hoop 1995). More generally speaking, it can be argued that context always restricts the domain of quantification. In the following quantified expression, context even completely determines the domain of quantification:

(2) Most were rejected

The noun which is supposed to provide the domain of quantification has been omitted. Hence, the domain of quantification in (2) is determined by the context, not by lexical information present in the sentence. In fact, any set of individuals can function as the domain of quantification in (2) as long as the linguistic or extra-linguistic context does not provide us with any clues on which interpretation is actually meant. As soon as the topic of conversation is the abstracts for the 1997 Amsterdam Colloquium, however, this mere fact restricts the set of possible domains of quantification in (2), due to the Gricean maxim `Be relevant'. In general, world knowledge may help to reduce the set of possible interpretations in the absence of other information. Compare (3a,b):

(3) a. Most ships unload at night
b. Most people sleep at night

The syntactic structures of the sentences in (3) are absolutely identical. Yet, the most unmarked interpretation for (3b) is that what most people do at night, is to sleep, whereas the most unmarked interpretation for (3a) is that most ships that unload, do it at night. Note that the reverse interpretations for the sentences in (3) are possible and emerge when the stress patterns are reversed. At this point, consider the sentence in (4):

(4) Most were rejected because of their LENGTH

In (4) there is no N' to provide the quantificational domain of *most*. If we want to derive the interpretation of (4) compositionally, we must assume the presence of an empty N' which content is identified by the context, or, alternatively, denotes the whole domain of individuals and gets intersected with a context set variable (Westerståhl 1985). But in fact, we need two context set variables then. One would be equated with the generalized union over the set of alternatives for the syntactic argument that contains the focus (Geilfu_ 1995, De Hoop and Solà 1996), such that the quantificational domain would become the set of things rejected because of some reason. The other one would be equated with some additional context set, e.g., the set of abstracts for the Eleventh Amsterdam Colloquium. Hence, what we get as the domain of quantification is something like (A/E _ X _ C). But how many contextual restrictions can or should we add before we may calculate the truth conditions of a quantificational sentence?

The data described above raise the question whether a line by line constructed compositional meaning based on syntactic structure is feasible at all. In this paper, we will investigate a different line of approach. We hypothesize that all possible sets in a model of the world may serve as sets between which a relation can be established by a given quantifier in a complex expression. Henceforth, we will refer to this hypothesis as the *Free Interpretation Hypothesis*, and generalize it to all types of arguments between which a semantic relation is established by a relational element in a sentence. The FIH does not imply that syntax does not play any role in the interpretation proces. Interpretations which are in accordance with the context and information structure of a sentence can still be eliminated if syntactic conditions are violated. As for determiners, the most important syntactic restriction is that if there is an N' that forms an NP together with the determiner, then this N' restricts the domain of quantification of the determiner. This by itself accounts for the fact noted w.r.t. (5) (Partee 1995) that the N' always restricts the domain of quantification, whether it contains an element in focus or not. The domain of quantification of *most* in (5) cannot be the set of people that sleep at night, therefore.

(5) Most LAZY people sleep at night

In other words, we do not need the introduction of a context set variable anymore.

Although the domain of quantification can often be put on a par with the topic or the background information, this is not necessarily so. The quantificational domain can also be entirely new, which would make it possible to omit the part that should provide the nuclear scope:

(6) Many women were rejected because of their height. And most men too

Comparatives

Viewing syntax as one of the ways to restrict interpretation, instead of as providing the structure that forms the basis for interpretation, also sheds new light on the interpretation of comparatives. Comparatives display a whole range of ellipsis phenomena. Subdeletion, Comparative Deletion, Comparative Ellipsis, Gapping and Null Complement Anaphora are only a few of the phenomena that can be observed in comparatives. With respect to these types of ellipsis, there appear to be three basic approaches. The first approach is to treat elliptical comparatives as reduced forms of clausal comparatives (cf. Hankamer 1973). A number of researchers have provided rather convincing evidence against such a deletion approach (see Hendriks 1995 for an overview). If it is assumed that reconstruction takes place under the same conditions as deletion, i.e. under identity, the reconstruction approach can be considered a notational variant of the deletion approach (Heim 1985). A second approach to ellipsis in comparatives is to assume a null proform occupies the position of the missing material (cf. Pinkham 1982). This null proform is anaphoric to previously occurring material. A strong argument against the null proform approach is the fact that the null proform must contain a variable to account for the interpretation of the comparative, which seems to go against the idea of a proform (as Johnson 1996 argues with respect to VP Ellipsis). More recently, a third approach has been put forward, according to which the elliptical *than*-phrase receives a direct interpretation (cf. Accuosto & Wonsever 1997, Gawron 1995). In this type of approach, the semantic representation of the `incomplete' *than*-phrase is completed on the basis of a partial semantics retrieved from the main clause.

All these approaches have in common the assumption that elliptical constructions are somehow more complex than the corresponding `full' constructions. This is reflected in the necessity for special deletion operations in the deletion approach, for licensing conditions in the null proform approach, and for complex lexical categories and discontinuous operators in a categorial type logic approach. However, if elliptical constructions are more complex than their `full' counterparts, why would a speaker ever consider leaving a word or phrase unexpressed? Moreover, ellipsis may cause ambiguity, which is undesirable from a communicative perspective. There does not seem to be any obvious reason why ellipsis would occur in natural language expressions. We will argue that elliptical constructions are the more simple type of constructions, and are not derived from their `full' counterparts. The argument will take three forms: (1) more lexical material can be omitted than can be accounted for by the various approaches, (2) in certain phrasal comparatives, it is impossible to find a correlate in the main clause to match the material in the *than*-phrase, and (3) there exist `reduced' comparatives for which no corresponding `full' comparative is possible on semantic grounds.

Standardly, a comparative is assumed to denote a relation between two relations. These two relations are relations between individuals and degrees or quantities, the first one expressed by the *than*-clause and the other one by the main clause. The semantic properties of the construction are determined by the comparative operator (*more*, *less*, *fewer*, *-er*, etc.). A comparative operator therefore resembles a determiner in that it also denotes a relation. If it is possible in a quantified expression to omit the N' which serves as the quantificational domain of the determiner, it should also be possible to omit one of the clauses in a comparative, for example the *than*-clause. As it turns out, this is not only possible but even preferable. Rayner & Banks (1990) conducted a small corpus analysis on Swedish and English texts to investigate the relative frequency of the various comparative constructions. They found that almost 40% of the comparatives they encountered were comparatives without a *than*-clause or *than*-phrase, as in (7):

(7) Jane is taller
(8) Jane ran faster than Jacky

Another 40% consisted of phrasal comparatives like (8), in which *than* is followed by a phrase of the lexical category NP, AP, Adv or PP. Finally, only 6% of the comparatives were `full' clausal comparatives.

In (7), the first relation is between Jane and a certain degree of tallness. The second relation is between one or more individuals salient in the context, and another degree of tallness. This second relation is determined pragmatically. Given the right context, it is also possible to omit the first relation instead:

(9) Is Jane taller than Jacky? No, than Robert

So, both in quantificational sentences and in comparatives, the first argument as well as the second argument can be left implicit. In fact, it is even possible that the semantic relation is itself the only new information of an utterance. In that case, both arguments should be recoverable from the context and need not be expressed lexically, depending on syntactic restrictions which may differ across languages (cf. Vallduví 1990):

(10) Many boys were rejected. In fact, most!
(11) Jane is taller than Jacky. No, shorter!

One major problem for a strictly compositional approach of comparatives would be the difference in interpretation between a *than*-phrase comparative such as the one in (8) above and one such as in (12) below:

(12) Jane ran faster than the world record
(13) Jane's yacht was longer than I thought

Non-deletion approaches account for the interpretation of phrasal comparatives by matching the element contained in the *than*-phrase to a suitable element in the main clause. These two elements are generally referred to as `contrasted elements', `correlated elements' or `parallel elements'. However, no suitable contrasted or parallel element is present in the main clause in (12) and (13) to match the material contained in the *than*-phrase. Although in both (8) and (12) *than* is followed by an NP, noone will interpret them equally on the basis of their syntactic structure. A rather ad hoc way to solve this problem is to posit an implicit element in the main clause, such as for example the sentence operator *it is true that* in (13) (cf. Rayner & Banks 1990). Note that (12) is also problematic under a deletion approach, since it cannot be derived through deletion under identity.
How are elliptical comparatives interpreted, then? As Rayner & Banks note, there is a strong tendency to assume that comparison is always between different objects. This point becomes clear when we consider possible answers to the following question:

(14) Has any king ruled as long as Gustav V?

According to Rayner & Banks, the answer "Yes, Gustav V did" is considered to be very misleading by most people. So hearers try very hard to establish a comparison between two different objects when confronted with a comparative, even if the two objects are not explicitly given. Since hearers neither reconstruct a syntactic representation nor a semantic representation of the *than*-clause, context must play an essential role in establishing the missing object and the implicit semantic relation. This is in accordance with our FIH.
Another strong argument in favour of our view is the existence of `reduced' comparatives for which no corresponding `full' comparative is possible. Consider the following so-called multiple head comparative:

(15) Public transportation has become more efficient. Nowadays, fewer airlines carry more people

Although the second sentence in (15) contains two comparative operators (*fewer* and *more*) and hence involves two instances of comparison, no *than*-clause or *than*-phrase is present. In fact, no `full' *than*-clause can be construed to `complete' this sentence, as is shown by the unacceptability of (16):

(16) *Nowadays, fewer airlines carry more people than airlines carried people before

The impossibility to construe a `full' than-clause with the same meaning as (15) is caused by the infinite regress that would result from the two dependent instances of comparison (Hendriks 1994). That the two instances of comparison will be dependent can be seen by determining the objects that are being compared. Not two numbers of airlines in general are being compared, but rather two numbers of airlines that carry people are being compared (so transport-planes are not taken into account). Similarly, not just two numbers of people in general are being compared, but rather people who travel by plane. Because of the mutual dependency of the two instances of comparison, the clausal comparative in (16) is ruled out. Thus, a clausal counterpart of (15) is impossible on semantic grounds. Nevertheless, the multiple head comparative in (15) is fully interpretable.

Constraints on interpretation

Given the FIH, a very general pragmatic constraint will capture the fact that (sets of) individuals that are already available in the discourse are chosen as the implicit arguments of semantic relations denoted by determiners and comparatives. Then, what kind of restrictions will ensure that in the end only the right interpretation remains? The most important restriction on the argument selection of a relational expression can be derived from the context within which the sentence is used. The entire context should be consistent with the selected interpretation. We will discuss pragmatic, prosodic and syntactic constraints that play a role in the interpretation procedure, partially based on proposals in the literature by Beaver (1994), Van Deemter (1992), Hendriks en Dekker (1996), a.o.

We will furthermore show that certain well-known parallelism effects on interpretation are not the result of absolute syntactic, prosodic, or semantic/pragmatic constraints on identity (see also Van Leusen 1994, Williams 1997). To explain why some available arguments are more appropriate than others, we will argue that certain constraints on interpretation come into operation only when necessary to avoid ambiguity in interpretation. Parallelism constraints are soft or violable which means that they can be overruled in order to yield a proper interpretation. Hence, the derivation of the final (set of possible) interpretation(s) of an incomplete expression is not simply a matter of the syntactic or semantic properties of the elements in the sentence but it also involves taking into consideration alternative interpretations and decide whether these are to be preferred or not. If we assume that argument selection is essentially free, then certain conditions will assure the most unmarked interpretation to emerge as the preferred interpreation. Thus, we can account for the fact that the second argument set of the Dutch determiner *weinig* `few' in (17a) below can provide the quantificational domain of the determiner *de meesten* `most' in (17b), because the obvious alternative would give the contradictory interpretation of most women being men with beards or glasses:

(17) a. Er zijn in Nederland maar weinig vrouwen hoogleraar.
there are in the Netherlands only few women full professor

b. De meesten zijn nog altijd mannen met baarden of brillen
most are still always men with beards or glasses

References

Accuosto, P. & D. Wonsever (1997) `An analysis for Spanish comparatives in Categorial Grammar'. Paper presented at WOLLIC 4, Fortaleza, 1997.

Beaver, D. (1994) `Accommodating Topics'. P. Bosch & R. van der Sandt (eds.) *Focus & Natural Language Processing*, vol. 3, IBM, Heidelberg.

Deemter, K. van (1992) `Towards a Generalization of Anaphora'. *Journal of Semantics* 9, 27-51.

Gawron, J.M. (1995) `Comparatives, superlatives, and resolution'. *Linguistics & Philosophy* 18:4, pp. 333-380.

Geilfu_, J. (1995) *Über gewisse Fälle von Assoziation mit Fokus*. PhD dissertation, University of Tübingen.

Hankamer, J. (1973) `Why there are two than's in English'. *CLS* 9, pp. 179-191.

Hendriks, H. & P. Dekker (1996), `Links without Locations. Information Packaging and Non-Monotone Anaphora'. P. Dekker & M. Stokhof (eds.) *Proceedings of the Tenth Amsterdam Colloquium*, ILLC, Amsterdam.

Hendriks, P. (1994) `Multiple head comparison and infinite regress'. *WECOL* 5, pp. 117-131.

Hendriks, P. (1995) *Comparatives and Categorial Grammar*. PhD dissertation, University of Groningen.

Heim, I. (1985) `Notes on comparatives and related matters'. Unpublished manuscript, University of Texas.

Hoop, H. de (1995) `*Only* a matter of context?' M. den Dikken & K. Hengeveld (eds.) *Linguistics in the Netherlands 1995*, Benjamins, Amsterdam.

Hoop, H. de & J. Solà (1996) `Determiners, Context Sets, and Focus'. J. Camacho, L. Choueiri & M. Watanabe (eds.) *The Proceedings of the Fourteenth West Coast Conference on Formal Linguistics*, CSLI, Stanford.

Johnson, K. (1996) `When verb phrases go missing'. *Glot International* 2:5, pp. 3-9.

Leusen, N. van (1994) `The Interpretation of Corrections'. P. Bosch & R. van der Sandt (eds.) *Focus & Natural Language Processing*, vol. 3, IBM, Heidelberg.

Partee, B.H. (1995) `Quantificational Structures and Compositionality'. E. Bach, E. Jelinek, A. Kratzer & B.H. Partee (eds.) *Quantification in Natural Languages*, Kluwer, Dordrecht.

Pinkham, J. (1982) *The formation of comparative clauses in French and English*. Indiana University Linguistics Club, Bloomington, Indiana.

Rayner, M. & A. Banks (1990) `An implementable semantics for comparative constructions'. *Computational Linguistics* 16:2, pp. 86-112.

Vallduví, E. (1990) *The Informational Component*. PhD dissertation, University of Pennsylvania, Philadelphia.

Williams, E. (1997) `Blocking and Anaphora'. *Linguistic Inquiry* 28, 577-628.

Completeness of Compositional Translation

Herman Hendriks

Utrecht Institute of Linguistics OTS, Utrecht University
ILLC/Department of Philosophy, University of Amsterdam

Willem-Olaf Huijsen

Utrecht Institute of Linguistics OTS, Utrecht University

Abstract

In this paper we will show that the Rosetta interlingua approach to machine translation can be modeled as a compositional transfer translation system in which the grammars of the source language and the target language are generated many-sorted algebras and transfer is a set-valued homomorphism from the term algebra of the former to the term algebra of the latter. On the basis of this algebraic formalisation we are able to prove a result concerning the completeness of translation systems in this framework: we will prove that one can effectively compute a function from which the answer to the question whether the system produces at least one grammatical target-language translation for each expression in the source language can be read off directly.

The research reported in this paper has its roots in the Rosetta project, which was conducted at Philips Research Laboratories in Eindhoven in the Netherlands between 1985 and 1992 (see Rosetta 1994 for further reading). The Rosetta project took a principled approach to machine translation in that it adhered to the principle of compositionality: 'The interpretation of an expression is a function of the interpretations of its parts and of the way they are syntactically combined' (Partee 1984; cf. Chapter 7 of Montague 1974, Janssen 1986, and Gamut 1991, pp. 139ff).

Applied to translation, the principle requires that the translation of an expression be a function of the translations of its parts and of the way they are syntactically combined. To cut a long story short, we simply note here that the principle has the following formal consequences for translation systems:

• The *source-language grammar* is a many-sorted π-algebra $A = \langle (A_c)_{c \in C}, (F_\gamma)_{\gamma \in \Gamma} \rangle$ with generating family $H = (H_c)_{c \in C}$.

> A *many-sorted algebra* of *signature* π ('π-algebra', or 'many-sorted algebra of signature (S, Γ, π)' in the terminology of Janssen 1986) is a structure $\langle (A_s)_{s \in S}, (F_\gamma)_{\gamma \in \Gamma} \rangle$, where S is a non-empty set (of *sorts*); $(A_s)_{s \in S}$ is an indexed family of sets (A_s is the *carrier* of s); Γ is a set (of *operator indices*); π (the *type-assigning function*) assigns to each $\gamma \in \Gamma$ a pair $\langle \langle s_1, \ldots, s_n \rangle, s_{n+1} \rangle$, where $n > 0$, $s_1 \in S, \ldots, s_{n+1} \in S$; and $(F_\gamma)_{\gamma \in \Gamma}$ is

an indexed family (of *operators*) such that if $\pi(\gamma) = \langle\langle s_1, \ldots, s_n\rangle, s_{n+1}\rangle$, then F_γ is total function $F_\gamma : A_{s_1} \times ... \times A_{s_n} \to A_{s_{n+1}}$.

In the above algebra C is the set of *syntactic categories*: for each $c \in C$, A_c is the set of *expressions* of category c and H_c is the set of non-compound *basic expressions* of category c. Syntactic categories completely determine the syntactic properties of expressions in the following way: for each $\gamma \in \Gamma$, *syntactic rule* F_γ of type $\pi(\gamma) = \langle\langle c_1, \ldots, c_n\rangle, c_{n+1}\rangle$ is a total function $A_{c_1} \times \ldots \times A_{c_n} \to A_{c_{n+1}}$ that yields a compound expression a_{n+1} of category c_{n+1} for every sequence $a_1, \ldots, a_n$ of expressions of respective categories $c_1, \ldots, c_n$. The number n of expressions to which a syntactic rule must be applied is called its *arity*.

• In a completely analogous fashion, the *target-language grammar* is a many-sorted ω-algebra $B = \langle(B_d)_{d\in D}, (G_\delta)_{\delta\in\Delta}\rangle$ with generating family $K = (K_d)_{d\in D}$.

• The *translation* relation TL between A and B is defined in terms of a *transfer* relation TF between the corresponding term algebras $T_{A,H}$ and $T_{B,K}$.

Let π-algebra $A = \langle(A_s)_{s\in S}, (F_\gamma)_{\gamma\in\Gamma}\rangle$ be generated by $H = (H_s)_{s\in S}$. Then $T_{A,H}$, the *term algebra* of A with respect to H, is defined as the π-algebra $\langle(T_{A,H,s})_{s\in S}, (F^T_\gamma)_{\gamma\in\Gamma}\rangle$, where for all $s \in S$ and for all $\gamma \in \Gamma$: $T_{A,H,s}$ is the smallest set such that $\{[h] \mid h \in H_s\} \subseteq T_{A,H,s}$, and if $t_1 \in T_{A,H,s_1}, \ldots, t_n \in T_{A,H,s_n}$ and $\pi(\gamma) = \langle\langle s_1, \ldots, s_n\rangle, s_{n+1}\rangle$, then $F^T_\gamma(t_1, \ldots, t_n) \in T_{A,H,s_{n+1}}$, where $F^T_\gamma(t_1, \ldots, t_n) = [F_\gamma t_1 \ldots t_n]$.

The carriers of $T_{A,H}$ consist of symbols which can be seen as representations of the derivational histories of A. These symbols are related to the members of the carriers of A by means of the *evaluate* function, which is defined as follows: $evaluate([h]) = h$, and $evaluate([F_\gamma t_1 \ldots t_n]) = F_\gamma(evaluate(t_1), \ldots, evaluate(t_n))$. Note that $a \in A_s$ if and only if there is a term $t \in T_{A,H,s}$ such that $evaluate(t) = a$.

For modeling Rosetta's morphosyntactic analysis of expressions e and its morphosyntactic generation of terms t, we will employ the respective sets $\{t \mid evaluate(t) = e\}$ and $\{e \mid evaluate(t) = e\}$.

We assume that a *transfer base* Π associates every basic expression h in $(H_c)_{c\in C}$ with a set $\Pi(h)$ of basic expressions k in $(K_d)_{d\in D}$ and every n-ary syntactic rule F_γ in $(F_\gamma)_{\gamma\in\Gamma}$ with a set $\Pi(F_\gamma)$ of n-ary syntactic rules G_δ in $(G_\delta)_{\delta\in\Delta}$.

In this respect Rosetta differs from Montague semantics, where basic expressions and syntactic rules are usually asociated with exactly one meaning and semantic rule, respectively. Another difference is that Montague semantics allows the association of basic expressions with non-basic meanings and the association of syntactic rules with polynomial operations over the rules actually present in the semantic component.

As a consequence, Rosetta is a system of *isomorphic* translation: it is only capable of accounting for the translation equivalence of syntactic derivation trees—where two trees are translation equivalent iff they have at least one meaning in common—to the exact extent that these trees are isomorphic and contain translation-equivalent basic expressions and syntactic rules at corresponding positions—cf. below.[1]

Based on this transfer base, the transfer of a term t is defined as $\mathrm{TF}([h]) = \{[k] \mid k \in \Pi(h)\}$ and $\mathrm{TF}([F_\gamma t_1, \ldots, t_n]) = \{[G_\delta t'_1, \ldots, t'_n] \mid t'_1 \in \mathrm{TF}(t_1) \wedge \ldots \wedge t'_n \in \mathrm{TF}(t_n) \wedge G_\delta \in \Pi(F_\gamma)\}$. Let the *morphosyntactic analysis* of an expression e be the set $\mathrm{MA}(e) = \{t \mid \mathit{evaluate}(t) = e\}$ and let the *morphosyntactic generation* of a term t be the set $\mathrm{MG}(t) = \{e \mid \mathit{evaluate}(t) = e\}$. Then the *translation* of an expression e is the set $\mathrm{TL}(e) = \{e' \mid t \in \mathrm{MA}(e) \wedge t' \in \mathrm{TF}(t) \wedge e' \in \mathrm{MG}(t')\}$.

In fact, by composing the notions of *semantic analysis* and *semantic generation* into the single one of *transfer*, the present set-up in fact manages to skip the common semantic component of source language and target language which is used as an interlingua in the Rosetta set-up, where source-language and target-language terms are *translation equivalent* if and only if they have at least one interpretation (i.e., semantic derivation tree) in common.

Given an interpretation relation I which associates every basic expression h with a set $I(h)$ of basic meanings m and every n-ary syntactic rule F_γ with a set $\Pi(F_\gamma)$ of semantic rules M_β, let a semantic derivation tree d *mirror* a syntactic derivation tree t iff $d = [m]$, $t = [h]$ and $m \in I(h)$; or $d = [M_\beta d_1 \ldots d_n]$, $t = [F_\gamma t_1 \ldots t_n]$, $M_\beta \in I(F_\gamma)$, and $d_1, \ldots, d_n$ mirror $t_1, \ldots, t_n$, respectively; let the semantic analysis $\mathrm{SA}(t)$ of a syntactic derivation tree t in $T_{A,H}$ yield the set $\{d \mid d \text{ mirrors } t\}$ of semantic derivation trees that mirror it; and let the semantic generation $\mathrm{SG}(d)$ of a semantic derivation tree d yield the set $\{t \mid d \text{ mirrors } t\}$ of semantic derivation trees t in $T_{B,K}$ that it mirrors.

If we then define $k \in \Pi(h)$ iff $I(h) \cap I(k) \neq \emptyset$ and $G_\delta \in \Pi(F_\gamma)$ iff $I(F_\gamma) \cap I(G_\delta) \neq \emptyset$ for basic expressions h of A and k of B as well as for syntactic rules F_γ of A and G_δ of B, we have that for all syntactic trees t in $T_{A,H}$: $\{t' \mid d \in \mathrm{SA}(t) \wedge t' \in \mathrm{SG}(d)\} = \{t' \mid d \text{ mirrors } t \wedge d \text{ mirrors } t'\}$ $= \mathrm{TF}(t)$. Thus both set-ups define the same translation relation.

A crucial question about a translation system concerns its *completeness*: does it assign at least one translation to each (term associated with an) expression in the source language?

Note that morphosyntactic analysis of an expression always yields at least one term (otherwise the expression would not be a grammatical one) and that morphosyntactic generation from a term yields exactly one expression by definition. Hence we can focus on the question of completeness of the transfer relation between terms.

We will show that one can effectively compute a function Φ from which the answer to this question can be read off directly. First, let '$t : s$' abbreviate 'term t is of sort s', let $\mathrm{TS}(t) = \{s \mid t' \in \mathrm{TF}(t) \wedge t' : s\}$, and recall that C and D are the respective sets of sorts of the source language and of the target language.

[1] Current work by the present authors, for that matter, reveals that a generalization to, e.g., *polynomial* translation will not affect the completenes results obtained here.

Lemma 1a:

$\mathrm{TS}([h]) = \{d \mid [k] \in \Pi(t) \wedge [k] : d\}$.

Lemma 1b:

$\mathrm{TS}([F_\gamma t_1, \ldots, t_n]) = \{d \mid G_\delta \in \Pi(F_\gamma) \wedge \omega(\delta) = \langle\langle d_1, \ldots, d_n\rangle, d\rangle \wedge d_1 \in \mathrm{TS}(t_1) \wedge \ldots \wedge d_n \in \mathrm{TS}(t_n)\}$.

Proof:

Straightforward.

Next, we define an infinite sequence of functions $\varphi_0, \varphi_1, \ldots$, where for all $k \in \mathbb{N}$: $\varphi_k : C \rightarrow \mathcal{P}(\mathcal{P}(D))$, such that for all $c \in C$ and for all $k \in \mathbb{N}$:

$\varphi_0(c) = \{\{d \mid k \in \Pi(h) \wedge k : d\} \mid h \in H_c\}$

$\varphi_{k+1}(c) = \varphi_k(c) \cup \Delta_{k+1}(c)$, where $\Delta_{k+1}(c) = \{\{d \mid G_\delta \in \Pi(F_\gamma) \wedge \omega(\delta) = \langle\langle d_1, \ldots, d_n\rangle, d\rangle \wedge d_1 \in D_1 \wedge \ldots \wedge d_n \in D_n\} \mid \gamma \in \Gamma \wedge \pi(\gamma) = \langle\langle c_1, \ldots, c_n\rangle, c\rangle \wedge D_1 \in \varphi_k(c_1) \wedge \ldots \wedge D_n \in \varphi_k(c_n)\}$.

Finally, we define for all $c \in C$:

$\Phi(c) = \bigcup_{k \in \mathbb{N}} \phi_k(c)$.

Claim 1:

For all $c \in C$ and $C' \subseteq C$: $C' \in \Phi(c)$ iff $C' = \mathrm{TS}(t_c)$ for some t_c.

Proof:

'Only if' by induction on the smallest $k \in \mathbb{N}$ such that $C' \in \varphi_k(c)$; 'if' by induction on the complexity of term t_c. (Use Lemma 1a for the bases and Lemma 1b for the induction steps.)

Corollary:

Completeness holds iff for all $c \in C$: $\emptyset \notin \Phi(c)$.

We now prove that Φ can be computed effectively.

Lemma 2:

If for all $c \in C$: $\varphi_k(c) = \varphi_{k+1}(c)$, then for all $c \in C$: $\varphi_{k+1}(c) = \varphi_{k+2}(c)$.

Proof:

If for all $c \in C$: $\varphi_k(c) = \varphi_{k+1}(c)$, then for all $c \in C$ and $D' \subseteq D$: $D' \in \varphi_k(c)$ iff $D' \in \varphi_{k+1}(c)$. Hence $\Delta_{k+1}(c) = \Delta_{k+2}(c)$, so that $\varphi_{k+1}(c)$

$= \varphi_k(c) \cup \Delta_{k+1}(c) = (\varphi_k(c) \cup \Delta_{k+1}(c)) \cup \Delta_{k+1}(c) = \varphi_{k+1}(c) \cup \Delta_{k+1}(c)$
$= \varphi_{k+1}(c) \cup \Delta_{k+2}(c) = \varphi_{k+2}(c)$.

Corollary:

If for all $c \in C$: $\varphi_k(c) = \varphi_{k+1}(c)$, then for all $n \in \mathbb{N}$: $\varphi_k(c) = \varphi_{k+n}(c)$ $= \Phi(c)$.

Claim 2:

For all $c \in C$ and $k \geq |C| \cdot 2^{|D|}$: $\varphi_k(c) = \Phi(c)$.

Proof:

For all $c \in C$ and $k \in \mathbb{N}$: $\varphi_k(c) \subseteq \varphi_{k+1}(c)$, so if $\varphi_k(c) \neq \varphi_{k+1}(c)$, then $\varphi_{k+1}(c)$ contains at least one additional element in comparison to $\varphi_k(c)$. Since $\varphi_k(c) \subseteq \mathcal{P}(D)$, also $|\varphi_k(c)| \leq |\mathcal{P}(D)| = 2^{|D|}$. Hence there are at most $2^{|D|}$ values for k such that $\varphi_k(c) \neq \varphi_{k+1}(c)$. Since there are $|C|$ sorts c, the number of values for k such that $\varphi_k(c) \neq \varphi_{k+1}(c)$ for at least one sort c is maximally $|C| \cdot 2^{|D|}$. In view of Corollary 2, these values for k must constitute a consecutive sequence of natural numbers starting with 0. So, for all $c \in C$ and $k \geq |C| \cdot 2^{|D|}$: $\varphi_k(c) = \Phi(c)$.

This result can be optimized, since it can be shown that for $k = |\Gamma|$, the number of source-language syntactic operators F_γ, it already holds that $\varphi_k(c) = \varphi_{k+1}(c)$ for all $c \in C$.

References

Gamut, L.T.F. (1991), *Logic, Language and Meaning. Volume II: Intensional Logic and Logical Grammar*. University of Chicago Press, Chicago and London.

Janssen, T. (1986), *Foundations and Applications of Montague Grammar. Part 1: Philosophy, Framework, Computer Science*. CWI Tract 19, Amsterdam.

Montague, R. (1974), *Formal Philosophy. Selected Papers of Richard Montague*. R. Thomason (ed.). Yale University Press, New Haven.

Partee, B. (1984), 'Compositionality'. In F. Landman and F. Veltman (eds.), *Varieties of Formal Semantics. Proceedings of the Fourth Amsterdam Colloquium*. Foris, Dordrecht.

Rosetta, M.T. (1994), *Compositional Translation*. Kluwer, Dordrecht.

An Intensional Version of Existential Disclosure

Martin Honcoop
Leiden University/Holland Institute of Generative Linguistics

Abstract. In Dynamic Semantics, Existential Disclosure (ED) allows us to address an indefinite as though it denotes a property. Current definitions of this operation entail that ED will not yield the intended result in opaque contexts, as intensional expressions create *inaccessible* domains for dynamic anaphora. Focusing primarily on Propositional Attitude Verbs (PAVs), we will show that this makes the wrong prediction for most PAVs. We will then argue that this situation can be improved upon i) by assuming an intensional version of ED which involves a discourse marker ranging over functions from ⟨state,world⟩ pairs to Context Change Potentials (CCPs), and ii) by assuming that so-called *volunteered-stance* PAVs introduce the CCP denoted by their complement clause as a discourse referent. The remaining class of PAVs on the other hand presuppose that the proposition expressed by their complement clause is part of the common ground. Therefore, an intensional version of ED will not help for these PAVs, as desired.

1 A Standard Definition of Existential Disclosure

One of the trademarks of Dynamic Semantics is its uniform representation of the semantics of 'simple' indefinites in terms of dynamic existential quantification. However, it is a well-known fact that 'simple' indefinites can exhibit a rather chameleonic behaviour. For example, the meaning of (1a), as represented in (1b), suggests that the indefinite *a mouse* is interpreted as a restricted variable, rather than as an existential quantifier.[1]

(1) a Most of the times, when Tom sees a mouse$_d$, he tries to catch it$_d$
b **Most**x: **sees´**(**tom**,x) ∧ **mouse´**(x) (**tries-to-catch´**(**tom**,x))

To account for cases such as (1), Dekker (1990,1993) proposes an operation

[1] Throughout this paper, it is assumed that the static meaning of an *n*-placed predicate **P´** denotes a function from an *n*-tuple of individuals to a set of worlds. Thus, $\mathbf{P}' = \lambda x_1 \ldots \lambda x_n \lambda w\, [\mathbf{P}_w(x_1) \ldots (x_n)]$ is of type $\langle e_1, \langle \ldots \langle e_n, p \rangle \ldots \rangle\rangle$, where $p = \langle w,t \rangle$ (where a possible world is of type *w*). The standard semantic types for other types of expressions should be adjusted accordingly. For example, a static Generalized Quantifier is of type $\langle\langle e,p\rangle,p\rangle$.

which is the exact mirror image of Existential Closure in DRT-based approaches: Existential Disclosure (ED). I will assume some familiarity with Chierchia's (1995) implementation of Groenendijk & Stokhof's (1989) (henceforth: G&S) Dynamic Montague Grammar (DMG).[2] Within this dynamic setting, Existential Disclosure can be defined as follows.

(2) **Definition 1: Existential Disclosure**

$\underline{\lambda}$ d [ϕ] $=_{def}$ λd´ [[ϕ] $\underline{\wedge}$ $\uparrow$d = d´] (where *d´* is not free in ϕ)

The definition in (2) enables us to dissolve a dynamic existential quantifier in the semantics. A simple illustration of this is provided in (3).

(3) a $\underline{\lambda}$d [$\underline{\exists}$d [$\uparrow$**mouse´**(d) $\underline{\wedge}$ $\uparrow$**sees´**(**tom**,d)]]
b λd´ [$\underline{\exists}$d [$\uparrow$**mouse´**(d) $\underline{\wedge}$ $\uparrow$**sees´**(**tom**,d)] $\underline{\wedge}$ $\uparrow$d = d´] (def. 2)
c λd´ [$\underline{\exists}$d [$\uparrow$**mouse´**(d) $\underline{\wedge}$ $\uparrow$**sees´**(**tom**,d) $\underline{\wedge}$ $\uparrow$d = d´]] (def. of $\underline{\exists}$ and $\underline{\wedge}$)
d λd [$\uparrow$**mouse´**(d) $\underline{\wedge}$ $\uparrow$**sees´**(**tom**,d)] (elementary logic)

Thus, if we represent the static content of (1a) as (4), we can account for the 'restricted-variable' interpretation of *a mouse* without being forced to abandon the general view that the semantics of 'simple' indefinites can invariably be represented in terms of dynamic existential quantification (**Most**^{D} is the dynamic counterpart of **Most**).

(4) $\downarrow$**Most**^{D}($^\wedge\underline{\lambda}$d [$\underline{\exists}$d [$\uparrow$**mouse´**(d) $\underline{\wedge}$ $\uparrow$**sees´**(**tom**,d)]])($^\wedge\lambda$d [$\uparrow$**tries-to-catch-it´**(**tom**,d)])

2 Existential Disclosure Meets Weak Islands

For ED as defined in (2) to do its job properly, $\underline{\exists}$x in ϕ must be able to bind an occurrence of the discourse marker *d* which occurs outside of its syntactic scope. It is well-known that this type of binding is constrained by *inaccessibility*. For example, the indefinite *a(ny) man* in (5) cannot bind the pronoun *he* on account of the fact that sentence negation creates an inaccessible domain for dynamic anaphora.

(5) *John didn't see a(ny) man$_{d}$. He$_{d}$ was wearing a pink suit.

We therefore expect (6a) below not to be equivalent to the dynamic property

[2] However, unlike Chierchia, we will retain the use of G&S's *state-switchers*. Their usefulness will become clear later on.

represented in (6b) And indeed, the non-equivalence of these two formulae follows directly from the fact that $\underline{\neg}$ (= $\uparrow\neg\downarrow$) is *externally static* in the sense of G&S. In general then, the definition in (2) entails that ED does not yield the intended semantic result in inaccessible domains for dynamic anaphora.

(6) a $\underline{\lambda}d\ [\underline{\neg\exists}x\ [\uparrow\mathbf{P}'(x)]]$ $\not\equiv$
b $\lambda d\ [\underline{\neg}\uparrow\mathbf{P}'(x)]$

As I have extensively argued elsewhere (cf. Honcoop 1996,forthcoming), this property of ED has nice pay-offs when examing Weak Island effects in a variety of constructions. Consider the 'wat voor'-split construction in Dutch, as exemplified in (7a) below. Here, the so-called indefinite *remnant* 'voor een boek' denotes the property of being a subkind of book which is predicated over the kind-variable quantified over by the *wh*-operator *wat*. If we want to account for this interpretation in DMG, we must apply ED in the way indicated roughly in (7b) (**kind-of book**$'$ = $\lambda\kappa\lambda w\forall x\forall w'{\sim}w\ [R_{w'}(x,\kappa) \rightarrow$ $\mathbf{book}_{w'}(x)]$, where R is the realization-relation holding between individuals and kinds; cf. Carlson 1977). In view of the fact that (7b) and (7c) are equivalent, this is unproblematic.

(7) a Wat heeft Jan voor een boek gelezen? ("What kind of book did Jan read?")
b $\mathbf{What}^{D}({}^{\wedge}\underline{\lambda}\kappa\ [\underline{\exists}\kappa\ [\uparrow\mathbf{kind\text{-}of\text{-}book}'(\kappa)\ \underline{\wedge}\ \uparrow\mathbf{read}'(\mathbf{jan},\kappa)]])$ $\equiv$ (cf. 2)
c $\mathbf{What}^{D}({}^{\wedge}\lambda\kappa\ [\uparrow\mathbf{for\text{-}book}'(\kappa)\ \underline{\wedge}\ \uparrow\mathbf{read}'(\mathbf{jan},\kappa)])$

However, in the light of the above, we now predict that problems will arise if some *X* intervenes between the *wh*-operator and its indefinite remnant, where *X* creates an inaccessible domain for dynamic anaphora. As testified by the ill-formedness of (8), this prediction is indeed borne out. Given that the indefinite remnant here cannot be properly construed as a property-denoting expression, and given that no other coherent interpretation can be imposed on this structure, (8) will be correctly ruled out.

(8) *Wat heeft Jan niet voor een boek gelezen? ("... didn't ...")

This line of reasoning goes a long way in explaining the sensitivity of 'wat voor'-split to Weak Islands. Unfortunately, if we stick to the definition of ED in (2), not all the way.

3 An Intensional Version of Existential Disclosure

A dynamic account of the sensitivity of 'wat voor'-split to Weak Islands is in immediate danger if the *wh*-operator 'wat' can be subextracted across an inaccessible domain for dynamic anaphora. The contrast in (9) therefore means red alarm. As is well-known, intensional contexts block dynamic anaphora, as shown in (9a). On the other hand, the intensional context induced by the Propositional Attitude Verb (PAV) *denken* ("to think") does not interfere with 'wat voor'-split, not even on a *de dicto* construal of the indefinite remnant, as indicated in (9b). In general, none of Cattell's (1978) so-called *volunteered-stance* PAVs (*geloven* "to believe", *beweren* "to claim", *veronderstellen* "to assume", and so on) disrupts subextraction of 'wat' in 'wat voor'-split constructions.

(9) a *John thought he met a photomodel$_i$ yesterday. She$_i$ smiled at him.
b Wat denkt Jan dat Peter voor een monster heeft gezien?
"What kind of monster does Jan think that Peter saw?"

I suggest that our earlier definition of ED in (2) above needs to be modified. Ideally, this modification preserves our earlier story as to what is wrong with sentences such as (8). A key observation that can be made in this respect concerns the following: anaphoric dependencies that span intensional domains can be saved if there is an appropriate intensional operator which scopes over the pronoun. To wit, (9a) contrasts with (10). This phenomenon is referred to as *modal subordination* (cf. Roberts 1987,1995).

(10) John thought he met a photomodel$_i$ yesterday. He thought she$_i$ smiled at him

Inspired by G&S's compositional approach to modal subordination, I will show that the observations in (9) can be accounted for by employing an intensional variant of (2) which involves a free discourse marker D ranging over functions from ⟨state,world⟩ pairs to CCPs (i.e. D is of type ⟨s,⟨w,cc⟩⟩, where cc = ⟨⟨s,p⟩,p⟩). Our intensional version of ED is presented in (11). It is relatively easy to show that (11), just like (2), enables us to semantically deactivate a dynamic existential quantifier on the following assumptions: i) the domain of individuals E is the same for all worlds; ii) '=' denotes $\{\langle a,a\rangle: a \in E\}$ in all worlds; and iii) $\downarrow{}^{\vee}D(w)$ is true of at least one world.

(11) **Definition 2: Existential Disclosure**
$\underline{\lambda} d\ [\phi] =_{def} \lambda d'\ [[\phi]\ \underline{\wedge}\ \uparrow\lambda w \forall w'\ [\downarrow [{}^{\vee}D(w)\ \underline{\rightarrow}\ \uparrow d = d'](w')]]$
(where d' is not free in ϕ)

To put (11) to work, we must furthermore assume that a PAV such as *think* introduces the CCP denoted by its complement (as restricted to the believe-worlds of the subject in a world *w*) as a dicourse referent. This assumption can be implemented formally by means of *state-switchers* as in (12) below, where $DOX'_w(x)(w') = \lambda w' [DOX_w(x,w')]$ denotes the set of all worlds w' that are *doxastically accessible* to w for x. Intuitively, a state-switcher $\{x/d\}$ performs the following task: if $\{x/d\}\phi$ is interpreted in a state s, then ϕ will be interpreted in a state which is just like s except that d will be assigned the value of x in s (cf. G&S).

(12) *think* ↦ (translates as) $\lambda\Pi\lambda x\lambda p\lambda w\ [\forall w'\ [DOX_w(x,w') \rightarrow \downarrow{}^{\vee}\Pi(w')] \wedge \{\ \lambda w\ [\uparrow DOX'_w(x) \underline{\wedge}\ {}^{\vee}\Pi]/D\}{}^{\vee}p(w)]$

Making sure that the discourse markers introduced by (11) and (12) are identical, we can at last disclose the indefinite remnant in (9b). Provided that in all of Jan's believe-worlds there is a kind of monster that Peter saw, we can prove the equivalence of in (13). In the context of (9b), the latter provision does not strike me as unnatural.

(13) $\downarrow\underline{\lambda}\kappa\lambda p\lambda w\ [\forall w'\ [DOX_w(\mathbf{jan},w') \rightarrow \exists\kappa\ [\mathbf{kind\text{-}of\text{-}monster}_{w'}(\kappa) \wedge \mathbf{saw}_{w'}(\mathbf{peter},\kappa)]] \wedge \{\ \lambda w\ [\uparrow DOX'_w(\mathbf{jan})\ \underline{\wedge}\ \underline{\exists}\kappa\ [\uparrow\mathbf{kind\text{-}of\text{-}monster}'(\kappa)\ \underline{\wedge}\ \uparrow\mathbf{saw}'(\mathbf{peter},\kappa)]]/D\}{}^{\vee}p(w)]$

(14) $\lambda\kappa\lambda w\ [\forall w'\ [DOX_w(\mathbf{jan},w') \rightarrow \mathbf{kind\text{-}of\text{-}monster}_{w'}(\kappa) \wedge \mathbf{saw}_{w'}(\mathbf{peter},\kappa)]]$

The kind-variable κ can now be properly quantified over by $\mathbf{What}^D$.

4 Other Propositional Attitudes, Weak Islands and Presupposition Projection

Both factive PAVs such as *regret* and Cattell's (1978) *response-stance* PAVs such as *confirm* do induce Weak Island effects on 'wat voor'-split, as (14) shows.

(14) *Wat betreurde/bevestigde Jan dat Peter voor een boek had gelezen?
"What kind of book did Jan regret/confirm that Peter read"

Thus, to prevent our intensional version of ED from applying successfully in these cases, we must assume that factive and response-stance PAVs i) quite like volunteered-stance PAVs, denote externally static functions, but ii) quite unlike volunteered-stance PAVs, do not introduce the CCPs denoted by their complements as discourse referents. Given that both factive and response-stance PAVs presuppose that the proposition expressed by their complements is part of the common ground (either as an indisputed fact or as a tentatively accepted claim), the latter assumption seems reasonable enough.

Consequently, cross-sentential anaphora involving factive and response-stance PAVS must be E-type. Since the resolution of E-type anaphora is determined by general mechanisms governing presupposition satisfaction, it follows that modal subordination involving factive and response-stance verbs should be analyzed as a byproduct of presupposition projection (say, along the lines of Heim 1992). On such an approach, it is correctly predicted that even though no intensional operator takes scope over it, a pronoun in a second clause can still be referentially dependent on an indefinite inside the scope of a factive PAV in the first clause (cf. 15, an example taken over from Asher 1987).

(15) John is happy that Fred has purchased a rabbit_i. It_i will keep him company.

(16) $\lambda c\, [[c + \lambda w\, [\mathbf{happy}_w(\mathbf{john}, \lambda w' \exists x\, [\mathbf{rabbit}_{w'}(x) \wedge \mathbf{has\text{-}purchased}_{w'}(\mathbf{fred}, x)])]] + \lambda w''\, [\mathbf{will\text{-}keep\text{-}company}_{w''}(\iota x\, [\mathbf{rabbit}_{w''}(x) \wedge \mathbf{has\text{-}purchased}_{w''}(\mathbf{fred}, x)], \mathbf{john})]]$

As shown in (16), any context *c* for which the update function corresponding to the first clause in (16) is defined is a context for which the update function corresponding to the second clause is defined.

Selective Bibliography

Cattell, R. (1978). 'On the Source of Interrogative Adverbs', In: *Language 54*, 61-77

Chierchia, G. (1995). *The Dynamics of Meaning*. Chicago University Press, Chicago.

Dekker, P. (1993). *Transsentential Meditations*. Ph.D. dissertation, University of Amsterdam.

Groenendijk, J. & M. Stokhof (1989). 'Dynamic Montague Grammar; A First Sketch'. ITLI Prepublication Series, University of Amsterdam.

Honcoop, M. (forthcoming). *Dynamic Excursions on Weak Islands*. Ph.D. dissertation, Leiden University/HIL.

Roberts, C. (1987). *Modal Subordination, Anaphora, and Distributivity*. Ph.D. dissertation, University of Massachusetts, Amherst.

Anaphora and Ellipsis in Type-Logical Grammar

Gerhard Jäger
Institute for Research in Cognitive Science
University of Pennsylvania, Philadelphia

1 Introduction

The aim of the present paper is to outline a unified account of anaphoricity and ellipsis phenomena within the framework of Type Logical Categorial Grammar.[1] There is at least one conceptual and one empirical reason to pursue such a goal. Firstly, both phenomena are characterized by the fact that they re-use semantic resources that are also used elsewhere. Secondly, they show a striking similarity in displaying the characteristic ambiguity between strict and sloppy readings. This supports the assumption that in fact the same mechanisms are at work in both cases.

(1) a. John washed his car, and Bill did, too.

b. John washed his car, and Bill waxed it.

In (1a), the second conjunct can mean that Bill washed Bill's car or that he washed John's car. Similarly, (1b) is ambiguous between a strict reading where Bill waxed John's and a sloppy/lazy one where he waxed his own car.

2 Structural Rules and Semantic Composition

One of the attractive features of Type-Logical Grammar is its commitment to a very strict correspondence between syntactic and semantic composition. Both are two sides of the same coin rather than two independent modules. Hence the decision for a particular syntax logic automatically restricts the possible ways of semantic combination. An instance of this tight connection is the fact that in grammars based on the associative Lambek calculus **L** (c.f. [7]) the meaning of a complex sign can be represented by a term of the typed λ-calculus where each meaning representation of a lexical item involved occurs once, and every λ-operator binds exactly one variable.

This seems to be too restrictive if we turn our attention to anaphora and ellipsis. Consider a simple elliptic sentence like

(2) a. John walked, and Bill did, too

b. $and'(walk'b)(walk'j)$

In its semantic representation, the meaning of the VP in the first conjunct occurs twice. There are several ways to deal with this fact. The source of this meaning duplication could be located in the lexical entry of *did*. For pronouns, this has been proposed in [11]. However, this treatment only captures bound pronouns in the sense of [10]. Since we want to maintain the option for a unified treatment of intra- and inter-sentential ellipses, this seems to be too narrow. Hence we are left with the need to allow duplicating meanings during syntactic composition.[2] In a Lambek-style grammar, this amounts to enriching **L** with the structural rules of Contraction and—since source and target of the ellipsis are not adjacent—Permutation, which results in **LPC**.

$$(3)\quad \frac{\Gamma[(\Delta,\Pi)] \Rightarrow t : A}{\Gamma[(\Pi,\Delta)] \Rightarrow t : A}[P] \qquad \frac{\Gamma[(x : A, y : A)] \Rightarrow t : B}{\Gamma[x : A] \Rightarrow t_{[y \leftarrow x]} : B}[C]$$

[1] As introductions to this theory of grammar, the interested reader is referred to [1, 8, 9]

[2] This has been proposed for pronouns already in [6] in the framework of Combinatory Categorial Grammar. Due to the intrinsic properties of this framework, Jacobson's proposal only captures bound pronouns, too.

For the time being, we treat *did* as a VP anaphor, and we follow [6] in considering the meaning of an anaphor to be the identity function. The essential steps of the derivation of (2) are (omitting redundant bracketing):

$$\cfrac{\cfrac{\cfrac{x:\mathbf{n}, y:\mathbf{n}\backslash\mathbf{s}, z:(\mathbf{s}\backslash\mathbf{s})/\mathbf{s}, u:\mathbf{n}, v:\mathbf{n}\backslash\mathbf{s} \Rightarrow z(vu)(yx):\mathbf{s}}{x:\mathbf{n}, y:\mathbf{n}\backslash\mathbf{s}, z:(\mathbf{s}\backslash\mathbf{s})/\mathbf{s}, v:\mathbf{n}\backslash\mathbf{s}, u:\mathbf{n} \Rightarrow z(vu)(yx):\mathbf{s}}[P]}{x:\mathbf{n}, y:\mathbf{n}\backslash\mathbf{s}, v:\mathbf{n}\backslash\mathbf{s}, z:(\mathbf{s}\backslash\mathbf{s})/\mathbf{s}, u:\mathbf{n} \Rightarrow z(vu)(yx):\mathbf{s}}[P]}{x:\mathbf{n}, y:\mathbf{n}\backslash\mathbf{s}, z:(\mathbf{s}\backslash\mathbf{s})/\mathbf{s}, u:\mathbf{n} \Rightarrow z(yu)(yx):\mathbf{s}}[C]$$

However, the unrestricted usage of Contraction would lead to a heavy over-generation (not to mention the effect of unrestricted Permutation). For instance, *John shows Mary* would be predicted to be a grammatical sentence with the meaning of *John shows Mary herself.* Therefore we have to impose constraints on the applicability of these rules to avoid such a collapse.

3 A Multi-Modal System

Research in recent years has shown that none of the pure categorial logics (like **NL**, **L**, **LP** or **LPC**) is well-suited for a comprehensive description of natural language, each of them by itself being either too restrictive or too permissive. That's why combinations of several systems have attracted much attention. In the simplest case, such a multi-modal logic has more than one n-place product connective together with the corresponding residuation connectives. Each family is characterized by the usual logical rules and a set of characteristic structural rules. In more elaborate systems, these different modes of composition are allowed to communicate via certain *interaction postulates.* This technique can be exploited to control the availability of Contraction and Permutation in the context of anaphora and ellipsis resolution.

Besides concatenation, we propose to use a second mode of combination "$\sim$" (with corresponding residuation operations $\hookleftarrow$ and $\hookrightarrow$). Formally, we augment **L** with the usual logical rules for $\hookleftarrow, \sim$, and $\hookrightarrow$. The bracketing of structured antecedent sequences corresponding to $\bullet$ and $\sim$ are denoted by $(\ldots)$ and $\{\ldots\}$ respectively henceforth.

In (4) the structural rules for the hybrid system **LA** (**L**ambek Calculus with **A**naphora) are given. "C" allows unrestricted Contraction for $\sim$. Permutation is distributed over three rules. Since $\sim$ can be thought of as combining an index with a constituent, the first two are dubbed "IM" for Index Movement and "IP" for Index Percolation. "P" assures that the collection of indices attached to a constituent form a multiset.

(4)
$$\frac{\Gamma[\{x:A, y:A\}] \Rightarrow t:B}{\Gamma[y:A] \Rightarrow t_{[x\leftarrow y]}:B}[C] \qquad \frac{\Gamma[(\Delta, \{\Pi, \Theta\})] \Rightarrow t:A}{\Gamma[(\{\Pi, \Delta\}, \Theta)] \Rightarrow t:A}[IM]$$

$$\frac{\Gamma[(\{\Pi, \Delta\}, \Theta)] \Rightarrow t:A}{\Gamma[\{\Pi, (\Delta, \Theta)\}] \Rightarrow t:A}[IP] \qquad \frac{\Gamma[\{\Pi, \{\Sigma, \Delta\}\}] \Rightarrow t:A}{\Gamma[\{\Sigma, \{\Pi, \Delta\}\}] \Rightarrow t:A}[P]$$

LA has two desirable logical properties, namely:

Fact 1

*(i) **LA** enjoys Cut Elimination.*

*(ii) **LA** is decidable.*

Sketch of Proof: An inspection of the inference rules of **LA** shows that the Cut Elimination algorithm from [7] in its extension by [4] carries over to **LA**. Due to Contraction, this does not guarantee decidability *per se*. But decidability does hold if we have an upper bound for the number of applications of Contraction in a proof. Such an upper bound can be obtained in the following way. There is an obvious translation from **LA** to **LPC** which preserves validity and proof term assignment (but not invalidity). Since proof search space for **LPC** is finite (c.f. [12]), there is only a finite number of potential proof terms for a given **LA**-sequent. Since proof terms code the number of applications of Contraction in a proof, this gives us the desired upper bound. ⊣

4 VP Ellipsis

To illustrate the system with a simple example, take the sentence

(5) John walks, and Bill does, too.

We assume the following lexical assignment:

(6)
- John–$j : \mathbf{n}$
- Bill–$b : \mathbf{n}$
- walks–$walk' : \mathbf{n} \backslash \mathbf{s}$
- and–$and' : (\mathbf{s} \backslash \mathbf{s})/\mathbf{s}$
- does–$\lambda x.x : (\mathbf{n} \backslash \mathbf{s}) \hookrightarrow (\mathbf{n} \backslash \mathbf{s})$

Starting with an **L**-derivable sequent, we obtain the following derivation (omitting redundant bracketings and intermediate steps):

(7)

$$\begin{array}{rcll}
x : \mathbf{n}, y : \mathbf{n} \backslash \mathbf{s}, z : (\mathbf{s} \backslash \mathbf{s})/\mathbf{s}, w : \mathbf{n}, r : (\mathbf{n} \backslash \mathbf{s}) & \Rightarrow & z(rw)(ux) : \mathbf{s} & [\hookrightarrow L] \\
\hline
x : \mathbf{n}, y : \mathbf{n} \backslash \mathbf{s}, z : (\mathbf{s} \backslash \mathbf{s})/\mathbf{s}, w : \mathbf{n}, \{v : \mathbf{n} \backslash \mathbf{s}, u : (\mathbf{n} \backslash \mathbf{s}) \hookrightarrow (\mathbf{n} \backslash \mathbf{s})\} & \Rightarrow & z(uvw)(ux) : \mathbf{s} & [IM] \\
\hline
x : \mathbf{n}, \{v : \mathbf{n} \backslash \mathbf{s}, y : \mathbf{n} \backslash \mathbf{s}\}, z : (\mathbf{s} \backslash \mathbf{s})/\mathbf{s}, w : \mathbf{n}, u : (\mathbf{n} \backslash \mathbf{s}) \hookrightarrow (\mathbf{n} \backslash \mathbf{s}) & \Rightarrow & z(uvw)(ux) : \mathbf{s} & [C] \\
\hline
x : \mathbf{n}, y : \mathbf{n} \backslash \mathbf{s}, z : (\mathbf{s} \backslash \mathbf{s})/\mathbf{s}, w : \mathbf{n}, u : (\mathbf{n} \backslash \mathbf{s}) \hookrightarrow (\mathbf{n} \backslash \mathbf{s}) & \Rightarrow & z(uyw)(yx) : \mathbf{s} &
\end{array}$$

After inserting the lexical meanings, we obtain the reading $and'((\lambda x.x)walk'\ b)(walk'\ j)$, which reduces to $and'(walk'\ b)(walk'\ j)$.
The mechanism works similar in the case of nominal anaphora. If we extend our lexicon with

(8)
- washed–$wash : (\mathbf{n} \backslash \mathbf{s})/\mathbf{n}$
- his–$\lambda xy.of'\ y\ x : \mathbf{n} \hookrightarrow (\mathbf{n}/\mathbf{cn})$
- car–$car' : \mathbf{cn}$

we derive the reading (9c) for (9a), corresponding to the provable sequent (9b).

(9) a. John washed his car.

b. $x : \mathbf{n}, y : (\mathbf{n} \backslash \mathbf{s})/\mathbf{s}, z : \mathbf{n} \hookrightarrow (\mathbf{n}/\mathbf{cn}), w : \mathbf{cn} \ \Rightarrow\ y(zxw)x : \mathbf{s}$

c. $wash'((\lambda xy.of'\ y\ x)j\ car')j\ (\ = wash'(of'\ car'\ j)j)$

Before we proceed to the interaction of VP ellipsis and anaphoricity, observe that (9) shows a spurious ambiguity. After (9b) is derived, we can either stop or apply the rule "\L", which gives us the sequent

(10) $y : (\mathbf{n} \backslash \mathbf{s})/\mathbf{s}, z : \mathbf{n} \hookrightarrow (\mathbf{n}/\mathbf{cn}), w : \mathbf{cn} \ \Rightarrow\ \lambda x.y(zxw)x : \mathbf{n} \backslash \mathbf{s}$

This means that it is possible to resolve the anaphor *his* against the subject argument place of *washed*, assigning the meaning $\lambda x.wash'(of'\ car'\ x)x$ to the VP *washed his car.*[3] In (9) this ambiguity is spurious since after combining this VP with the subject *John*, we end up with the meaning (9c) again.

[3] This can be seen as a reconstruction of Reinhart's ([10]) distinction between coreferential and bound pronouns.

(11) John washed his car, and Bill did, too.

In (11), on the other hand, this ambiguity, though spurious in the first conjunct, makes a difference for the interpretation of the second one. If we plug in (10) into the conclusion of (7) via the Cut rule, we immediately derive the sloppy reading of (11). This amounts to first resolving *his* against the subject argument place of *washed* and afterward resolving *did* against the VP derived in this way. If, on the other hand, *his* is resolved against *John* prior to resolution of *did*, the strict reading results.

5 Associativity?

[3] present an example of a cascaded ellipsis that allows to distinguish different ellipsis theories on a very fine-grained level.

(12) John revised his_1 paper before the teacher did [resolve his_2 paper], and Bill did [resolve his_3 paper before the teacher did resolve his_4 paper] too.

Among the six readings that are considered in [3], the present system generates four (*JJJJ, JJBB, JTJT, JTBT* as referents of the four occurrences of *he* respectively). This seems to be too few since in an appropriate contextual setting, JJBJ is a possible reading as well. The problem becomes even more obvious if we turn our attention to examples like the following (from [2]):

(13) John realizes that he is a fool, but Bill does not, even though his wife does.

An easy way to relax the constraints of the theory is to allow a lexical assignment like

(14) does–$\lambda x.x : (\mathbf{n} \hookrightarrow (\mathbf{n} \setminus \mathbf{s})) \hookrightarrow (\mathbf{n} \hookrightarrow (\mathbf{n} \setminus \mathbf{s}))$

for the first occurrence of *does*. This would enable us to resolve *it* against *realizes that he is a fool* **before** *he* is resolved. In this way, the silent *he* can be resolved independently from the overt one, yielding (among others) the desired reading. While it seems to be *ad hoc* to assume such a lexical ambiguity for *does*, this type assignment can be derived if we add the a version of the Geach Rule to our calculus:

$$x : A \hookrightarrow B \;\Rightarrow\; \lambda yz.x(yz) : (C \hookrightarrow A) \hookrightarrow (C \hookrightarrow B)$$

Inserting the identity function (as the lexical meaning of *does*) for x gives us the semantic term $\lambda yz.yz$ for the derived category, which is equivalent to $\lambda y.y$. In terms of sequent rules, this amounts to extending **LA** to a new system, call it **LAA**, which includes the structural rule of Associativity for both modes of combination:

(15) $$\frac{\Gamma[\{\Delta, \{\Pi, \Sigma\}\}] \Rightarrow t : A}{\Gamma[\{\{\Delta, \Pi\}, \Sigma\}] \Rightarrow t : A}[A\sim]$$

The decision between **LA** and **LAA** as appropriate calculus for anaphoricity and ellipsis is an empirical issue that has to be decided for each class of phenomena separately.
As far as English VP ellipsis is concerned, **LAA** predicts a very high degree of freedom. Besides the six readings for (12), it also admits readings like *JTTT* etc. Two comments are in order here. First, something similar to *JTTT* seems to be marginally possible indeed (judgments range from "impossible" to "perfect"):

(16) [Every bum on the streets of New York]$_j$ is more concerned about his_j safety than this crowd loving president Clinton_i is.

a. Fortunately for him_i, his_i bodyguard is too.

b. Fortunately for him_i, his_i bodyguard is more concerned about his_i safety than he_i is concerned about his_i safety.

Second, restrictions on anaphora resolution in constructions without ellipsis do not substantially differ from those with ellipsis. (17) shows exactly the same range of readings like (12).

(17) John revised his paper before the teacher revised his paper, and Bill revised his paper before the teacher revised his paper, too.

If *too* is understood as establishing a parallelism between *John* and *Bill*, we have just the same four or five readings we have in (12). This fact is well-known (see for instance [5]). One way to account for this is to assume that the deaccenting of the VPs in (17) that correspond to the elided material in (12) is the primary cause for this similarity. Ellipsis and deaccenting could be analyzed as largely two instances of the same phenomenon. Nevertheless another perspective is possible as well. The restrictions on anaphoric relationships that show up could be analyzed as consequences of the semantics/pragmatics of *too*, which simultaneously requires deaccenting of the second conjunct. This would make the differences between *and ... too*, *but*, *even though* etc. less mysterious. If such a line of research proves to be successful, this would allow a highly unrestrictive theory of ellipsis resolution like the one implied by **LAA**.

An **LAA** based account seems definitely to be preferable in the case of nominal anaphora, since this automatically captures *paycheck* pronouns.

(18) a. Bill spent his money, and John saved it.

b.
- spent–*spend'* : $(\mathbf{n} \setminus \mathbf{s})/\mathbf{n}$
- saved–*save'* : $(\mathbf{n} \setminus \mathbf{s})/\mathbf{n}$
- money–*money'* : **cn**

c. $and'(save'(of'money'j)j)(spend'(of'money'b)b)$

Most importantly, *it* can get the derived category $(\mathbf{n} \hookrightarrow \mathbf{n}) \hookrightarrow (\mathbf{n} \hookrightarrow \mathbf{n})$, again with the interpretation as identity functions (over Skolem functions). Hence *his money* with the pronoun still unresolved (which denotes the Skolem function from individuals to their cars) can serve as antecedent for *it*.

In the case of stripping, **LA** seems to be the appropriate logic, although judgments are somewhat fuzzy here. In (19a) all contextual factors favor a mixed sloppy/strict reading (as indicated in (19b)), which is nevertheless only very marginally possible.

(19) a. Every candidate believes that he can win, even Smith, but not his wife.

b. Every candidate believes that he can win, even Smith believes that he can win, but his wife does not believe that Smith can win.

6 Conclusion

In this paper, I have outlined a theory of anaphoricity and ellipsis which shows some desirable properties from a conceptual point of view:

- The semantics is fully compositional. As a consequence, there is no need for a level of Logical Form where ellipsis resolution takes place. Since ellipsis phenomena are usually considered to be a strong indication for the presence of LF, this might have consequences for grammar architecture as a whole. Neither does the theory presented here crucially depend on the typed λ-calculus as a semantic representation language. That it has been used throughout the paper is merely a matter of convenience; everything could be reformulated in terms of set theory or Combinatory Logic without loss of generality.

- The theory is variable free. This removes a great deal of arbitrariness from semantic derivations. In traditional theories, anaphora and ellipses are translated as variables (i.e. they denote functions from assignment functions to objects of the appropriate type). Since there are infinitely many variables, one and the same pronoun is predicted to be infinitely ambiguous. Though this is compatible with the letter of the Principle of Compositionality, it is clearly against its spirit, since identical expressions with identical syntactic structure should have identical denotations. Here, resolution ambiguities are treated as structural ambiguities, corresponding to essentially different proofs of the same sequent.
- The theory is modular. Anaphora and ellipsis resolution take place at the syntax-semantics interface, without reference to pragmatics. Since both phenomena are subject to syntactic and semantic constraints, the syntax-semantics interface seems to be the natural place to deal with them. This does not exclude that some of the readings generated there are filtered out later on pragmatic grounds. This is not surprising since the same holds for other sources of structural ambiguities like quantifier scope or focus projection.

References

[1] Bob Carpenter. *Type-Logical Semantics.* MIT Press, 1997.

[2] Östen Dahl. How to open a sentence. In *Logical Grammar Report*, number 12. University of Göteborg, 1974.

[3] Mary Dalrymple, Stuart M. Shieber, and Fernando C.N. Pereira. Ellipsis and higher-order unification. *Linguistics and Philosophy*, 14(4):399–452, 1991.

[4] Kosta Došen. Sequent systems and grupoid models I. *Studia Logica*, 47:353–389, 1988.

[5] Claire Gardent. Parallelism, HOU and deaccenting. Claus Report 85, 1997. Universität des Saarlandes, Saarbrücken.

[6] Pauline Jacobson. The syntax/semantics interface in categorial grammar. In Shalom Lappin, editor, *The Handbook of Contemporary Semantic Theory*, pages 89–116. Blackwell Publishers, 1996.

[7] Joachim Lambek. The mathematics of sentence structure. *American Mathematical Monthly*, 65:154–170, 1958.

[8] Michael Moortgat. Categorial type logics. In Johan van Benthem and Alice ter Meulen, editors, *Handbook of Logic and Language*, chapter 2, pages 93–178. Elesvier, MIT Press, 1997.

[9] Glynn Morrill. *Type Logical Grammar.* Kluwer, 1994.

[10] Tanya Reinhart. *Anaphora and Semantic Interpretation.* Croom Helm, 1983.

[11] Anna Scabolcsi. Bound variables in syntax (are there any?). In Renate Bartsch, Johan van Benthem, and P. van Emde Boas, editors, *Semantics and Contextual Expressions*, pages 295–318. Foris, 1989.

[12] Heinrich Theodor Wansing. *The Logic of Information Structure.* PhD thesis, Freie Universität Berlin, 1992.

A compositional semantics for the game-theoretical interpretation of logic

Theo M.V. Janssen, Computer Science, University of Amsterdam

Abstract
In a number of publications (e.g Hintikka (1996), Hintikka & Sandu (1997)) is argued for IF logic: a variant of game theoretical semantics for predicate logic in which information can be hidden. Hintikka claimed that no compositional semantics was possible for this logic. However, W. Hodges designed one (Hodges (1997*a*), Hodges (1997*b*)). Hodges formalization made clear that there are methods to use hidden information in an un expected way: by giving signals to oneself. The present contribution gives an alternative (called UF-semantics) that is compositional, but that considerably simpler, and tries to avoid such signals.

Introduction to game theoretical semantics
In game theoretical semantics the truth of a formula is determined by a game between two players, one who tries to check the formula, and one who tries to refute it. Hintikka calls the players Me and Nature, or Verifyer and Falsifyer, but we shall follow Hodges and call them ∃loise (female) and ∀belard (male). She tries to verify the formula, and he to falsify. The formula is 'true', if ∃loise has a winning strategy, and 'false' if ∀belard has a winning strategy. Note that 'not true' is not equivalent with 'false'.

An example is the game for $\forall x[\exists y x \neq y]$. It proceeds as follows. ∀belard choses a value for x, next ∃loise chooses a value for y. ∃loise wins if indeed $x \neq y$, and ∀belard wins if $x = y$. There is a strategy for ∃loise to win every game: look at ∀belard 's choice, and take a different value for y. Therefore the formula is true.

In IF logic (Independence Friendly logic) information can be hidden. For instance $(\exists y/x)$ means that the value of x is hidden when the value for y has to be chosen. Consider now $\forall x(\exists y/x)[x \neq y]$. When ∀belard has chosen, ∃loise does not know the value of x, and therefore there it is possible that she selects the same value. Hence ∃loise has no winning strategy,the formula is 'not true'. Because ∀belard has no winning strategy, it is not 'false' either.

A classical phenomenon for which this logic is used, is quantifier independence (often expressed by branching quantifiers). Consider

Some official of each company knows some aide of each senator

A (naive) straightforward representation of the meaning of this sentence would be (using self-explanatory abbreviations):

$$\forall x \exists y \forall z \exists w[C(x) \wedge S(z)] \rightarrow O(y,x) \wedge A(w,z) \wedge C(y,z)]$$

However, since $\exists w$ is within the scope of $\forall x$, this introduces an unwanted dependency between the aide and company the officer works for. In the situation described in the sentence the officer and the aide have a symmetric role. This semantic symmetry is restored by replacing $\exists w$ by $\exists(w/x)$.

This classical example is just one of the many arguments in favor of IF logic. Several fundamental arguments are given by Hintikka and others, and many applications.

Game Semantics for IL logic
W. Hodges cleared the way towards a compositional treatment of IF logic, and I will follow his syntax. That is powerful than the syntax of Hintikka, since it allows to hide any previously made choice, whereas Hintikka only allows to hide choices

of the other player. Below the syntax is presented, together with a description how the game proceeds when such a subformula is encountered. The logic has variables (for elements of the model), and indices (for selection from a parametrized set of predicates). By W a set ofsuch variables and indices is denoted.

$R_{ij...}(v_1, \dots, v_n)$	If for the chosen values for indices and variables the formula is true in the model, then ∃loise wins this.
$P(v_1, \dots, v_n)$	Analogously
$(\exists x/W)\psi$	∃loise chooses (a name for) an element of the model, but without taking into account previously chosen values for variables or indices in W. The game proceeds with ψ.
$(\forall x/W)\psi$	As before, but ∀belard makes the choice.
$\psi(\vee/W)\theta$	∃loise chooses one of ψ and θ, but without taking into account values chosen for variables or indices in W. The game proceeds with the chosen subformula.
$\psi(\wedge/W)\theta$	As before, but now ∀belard makes the choice.
$(\bigvee_{i\leq n}/W)\psi$	Here ψ may contain parameterized relation symbols like symbols $R_{ij...}$. ∃loise has to choose a value for i without knowing values for W, and the game proceeds with ψ.
$(\bigwedge_{i\leq n}/W)\psi$	Now ∀belard makes the choice.
$\neg\phi$	Classical negation: this formula is true if there is no winning strategy for ∃loise. Because of this interpretation, $\neg$ can occur only as the outermost operator of a sentence. Besides this negation one also finds the operator $\sim \phi$ in the literature, called 'game negation': the roles of the players are interchanged, both for winning and playing.

Discussion of Hodges' IF semantics

W. Hodges has designed a compositional semantics for IF-logic. We will not consider the technical details of his proposal, but focus one of his discoveries. It turned out that the ∃loise can base her strategy on her earlier choises which seem irrelevant at first sight. Some examples are discussed below; it will be assumed that the formulas are used in a situation where there are at least two elements: a and b (oherwise it makes not much sense to hide choices).

1. $\forall x \exists z (\exists y/x)[x \neq y]$
   A strategy for ∃loise has two decision points. One for $\exists z$, and one for $(\exists y/x)$. The occurrence of z seems to be completely irrelevant, because z does not occur. The strategy ∃loise takes for $(\exists y/x)$ is to choose y to be always equal to z. This strategy is independent of the current value for x, hence allowed. And the strategy for $\exists z$ is to choose a if x is not a, and to choose b otherwise. Hence $x \neq z$. Since $y = z$ it follows that $x \neq y$. So by following this strategy, ∃loise always wins, although the formula without the empty quantification is not true.
2. $\forall x(x = a \vee (\exists y/x)(x \neq y))$
   For $(\exists y/x)$ ∃loise always chooses a. For the disjunction her strategy is as follows. If x happens to be a, she chooses the left side of the disjunction (which then is true), and otherwise she chooses the right hand side (which then becomes true by her choice for y). This strategy makes the formula true.
3. $\forall x((\exists y/x)(x \neq y) \vee (\exists y/x)(x \neq y))$
   If $x = a$ then ∃loise chooses left, and there she has the strategy to choose b. Otherwise ∃loise chooses right, and there she always chooses a. In both cases the chosen disjunct is true. So this is a winning strategy, hence the formula is true, although without the repetition it is not true.

The last example exhibitsis a very strange property of IF logic: $\phi \vee \phi$ is not always equivalent with ϕ.

All these examples show that ∃loise has unexpected ways of winning. One might either that it 'is all in the game', or that she is cheating. The semantics of Hodges is based on the former opinion (he calls such examples 'deathtraps'). In his approach the Independence-Friendly aspect of $(\exists y/x)$ is formalized by choosing y independent of x. allowing dependency on any other value. The alternative presented below, is to formalize it in a Uniform-Friendly way: a value for y has to be choosen such that it works uniformly for all values of x, independently of the context. The UF semantics for the IF language will assign 'not true' to all above examples, and works all right for the linguistic examples with branching quantifiers. Further investigations have to learn whether it is also attractive in other aspects.

Preliminaries for UF semantics

We assume an infinite stack of variables, and for each n an infinite stack of choice-indices (of rank n). An assignment g assigns to each variable an element in the model, and to each index a number of at most its rank. Hence for a variable x we have $g(x) \in A$ and for an index i we have $g(i) = k$, where $1 \leq k \leq rank(i)$. The set of assignments is denoted by As. The interpretation $[\![\phi]\!]$ of a formula is a set of assignments; these are the assignments for which ∃loise has a winning strategy. For a closed formula $[\![\phi]\!]$ the interpretation is either As (if for all initial assignments ∃loise has a winning strategy), or $\emptyset$ (if she has no winning strategy).

Besides standard set-theoretical operators, two other operators are needed in the definition of $[\![\phi]\!]$:

$C_w(G) = \{g \in As \mid \text{there is } g' \in G \text{ such that } g' \sim_w g\}$

C_w adds to a set of assignments all w-variants. In the algebraic interpretation of predicate logic is called the wth-cylindrification operator. I can be seen as a w-uniform cylinder that fits over G.

$T_W(G) = \{g \in G \mid \text{for all } w \in W \text{ and all } g' \sim_w g \text{ holds } g' \in g\}$

T_W yields the assignments for which the values of variables and indices in W can vary arbitrarily, while still remaining in G. It can be seen as a W-uniform tube that fits in G. We shall write T_x instead of $T_{\{x\}}$. T_x would in the algebraic interpretation of predicate logic be the interpretation of the universal quantifier.

It can be shown that $\overline{C_x(G)} = T_x(\overline{G})$

Compositional UF Semantics for IF logic

Below, the compositional interpretation $[\![\phi]\!]$ is defined by an explicit function of the interpretation of its parts; also an explanation is given.

$[\![P(v_1,\ldots,v_n)]\!] = \{g \mid P^A(g(v_1),\ldots,g(v_n)) = true\}$

$[\![R_{i,j}(v_1,\ldots,v_n)]\!] = \{g \mid R_{g(i)g(j)\ldots}{}^A(g(v_1),\ldots,g(v_n)) = true\}$

$[\![\psi(\wedge/W)\theta]\!] = [\![\phi]\!] \cap [\![\theta]\!]$.

∀belard will make the choice between ψ or θ, so ∃loise should be prepared to make both conjuncts true.

$[\![\psi(\vee/W)\theta]\!] = T_W([\![\phi]\!]) \cup T_W([\![\theta]\!])$.

∃loise wil choose a disjunct without knowing values for W. So she can only choose from those assignments which work for all W. Hence she has a winning strategy for $\psi(\vee/W)\theta$ only for assignments in the union mentioned.

$[\![(\bigwedge_{i \leq n}/W)\psi]\!] = T_i([\![\psi]\!])$

If there are assignments which make $\psi(i)$ true for all values of i, then ∃loise can win, no matter what ∀belard will choose.

$[\![(\bigvee_{i \leq n}/W)\psi]\!] = \bigcup_{k \in \{1,\ldots,n\}} T_W(\{g \in [\![\psi]\!] \mid g(i) = k\})$

∃loise will choose an i value without knowing values for W. Therefore only those i come into consideration for which ψ can be made true W-uniformly.

$[\![(\forall v/W)\psi]\!] = T_v([\![\psi]\!])$

T_v selects the assignments which have such values for the free variables in ψ such that all their v-variants satisfy ψ. Only for those variables ∃loise has a winning strategy. ∃loise has no winning strategy.

$[\![\exists(v/W)\psi]\!] = C_v \bigcup_a T_W(\{g \in [\![\psi]\!] \mid g(v) = a\})$

Try a value a for v, and see whether ψ is W-uniformly true for the assigments which assign a to v. The the assignments in this set form a possible choice. Add to the thus found assignments all v-variants (because v is bound its value is irrelevant outside this subformula, whereas by going to ψ suitable values will be chosen).

$[\![\neg\psi]\!] = \overline{[\![\psi]\!]}$

Hodges remarks that problems arise with intuition concerning the game when $\neg$ arises freely inside formulas, and that Hintikka avoids these by restricting the occurrence of $\neg$. In a compositional approach this is not a desirable solution. Hodges defines $\neg$ by a compound operator involving $\sim$, and defines clauses for interchanged players which are related to the clauses given. But in the present context there is no reason to do so, and $\neg$ is interpreted in the classical way as complement.

Examples for UF semantics

$\forall x \exists(y/x)[x \neq y]$

- Its interpretation is defined as $T_x(C_y \bigcup_a T_x(\{g \in [\![x \neq y]\!] \mid g(y) = a\}))$
- So $[\![x \neq y]\!]$ is the set of assignments that give different values to x and y.
- Then $\{g \in [\![x \neq y]\!] \mid g(y) = a\}$ are the assignments that assign to x a value that differs from a.
- The x-uniform part of $\{g \in [\![x \neq y]\!] \mid g(y) = a\}$ is empty: there are no assignments in $\{g \in [\![x \neq y]\!] \mid g(y) = a\}$ for which x may vary arbitrarily while remaining in $\{g \in [\![x \neq y]\!] \mid g(y) = a\}$: the value a is disallowed. So $T_y(\{g \in [\![x \neq y]\!] \mid g(y) = a\}) = \emptyset$
- Since $\bigcup_a(\emptyset) = \emptyset$, also $C_y \bigcup_a(\emptyset) = \emptyset$. Consequently, there are no assignments in $[\![\exists(y/x)x \neq y]\!]$. The formula is ''not true' in all contexts.
- $T_x([\![\exists(y/x)x \neq y]\!]) = T_x(\emptyset) = \emptyset$. So the formula is not true.

$\forall x \exists z \exists(y/x)x \neq y$

- $[\![\exists z \exists(y/x)x \neq y]\!] = C_z(\bigcup_a T_\emptyset(\{g \in [\![\exists(y/x)x \neq y]\!] \mid g(z) = a\})) = C_z(\bigcup_a T_\emptyset(\emptyset)) = C_z(\emptyset) = \emptyset$. So the formula if not true.

$\forall x(x = a \vee (\exists y/x)(x \neq y))$

- $[\![x = a]\!] = \{g \mid g(x) = a\}$
- $[\![x = a \vee (\exists y/x)(x \neq y)]\!] = \{g \mid g(x) = a\} \cup \emptyset = \{g \mid g(x) = a\}$
- $[\![\forall x(x = a \vee (\exists y/x)(x \neq y))]\!] = T_x\{g \mid g(x) = a\} = \emptyset$. Hence the formula is not true.

$\forall x((\exists y/x)(x \neq y) \vee (\exists y/x)(x \neq y))$

- The interpretation is $T_x(\emptyset \cup \emptyset) = \emptyset$. Hence the formula is not true.

Comments on UF semantics

Below we mention some properties of UF semantics, and give some comments.

- The semantics presented in this paper is a compositional definition of *truth*. Using a related formalism a definition of *falsehood* could be given.
- The main claim of the paper is should of course be that ∃loise has a winning strategy in game ϕ for if and only if $[\![\phi]\!] = As$ The clauses of the semantics are accompagnied by explanation which describe what the strategy of ∃loise is when she encounters such a subformula. However, Hodges has the same result for another semantics. That illustrates that a proof of the claim cannot be given; it depends on strategies allowed: uniform or independent.
- The choice $W{=}\emptyset$ gives in all cases directly the classical algebraic interpretation. Interesting cases are:
  - $[\![\psi(\vee/\emptyset)\theta]\!] = T_\emptyset[\![\psi]\!] \cup T_\emptyset[\![\theta]\!] = [\![\psi]\!] \cup [\![\theta]\!]$, in particular is $[\![\psi \vee \psi]\!] = [\![\psi]\!] \cup [\![\psi]\!] = [\![\psi]\!]$. So in all contexts is $\psi \vee \psi$ equivalent with ψ.
  - $[\![(\exists v)\psi]\!] = C_v \bigcup_a T_\emptyset(\{g \in [\![\psi]\!] \mid g(x) = a\}) = C_v T_\emptyset([\![\psi]\!]) = C_v([\![\psi]\!])$, which is the standard compositional interpretation of existential quantification.
- The interpretation of the universal quantifier reads $[\![(\forall v/W)\psi]\!] = T_v([\![\psi]\!])$, and for existential quantifier: $[\![\exists(v/W)\psi]\!] = C_v \bigcup_a T_W(\{g \in [\![\psi]\!] \mid g(v) = a\})$ So there seems to be a asymmetry between the interpretation of ∀ and ∃. However, the following definition is equivalent to the one given before: $[\![(\forall v/W)\psi]\!] = T_v \bigcup_a(\{g \in [\![\psi]\!] \mid g(v) = a\})$
  This formulation has more resemblance. There is a symmetry between T_v and C_v as in algebraic intepretation of classical logic. The operator T_W which arises for ∃ only, reflects that there ∃loise has to choose a value, and her choice is restricted by the aim of winning.

Acknowledgements

I thank Peter van Emde Boas and especially Wilfrid Hodges for many useful discussions about the interpretation of IF logic.

References

Hintikka, J. (1996), *The principles of mathematics revisited*, Cambridge University Press, Cambridge.

Hintikka, J. & Sandu, G. (1997), Game-theoretical semantics, *in* J. van Benthem & A. ter Meulen, eds, 'Handbook of logic and language', Elsevier, Amsterdam and The MIT Press, Cambridge, Mass., chapter 6, pp. 361–410.

Hodges, W. (1997*a*), 'Compositional semantics for a language of imperfect information', *Journal of the IPGL* **5**(4), 539–563.

Hodges, W. (1997*b*), Some strange quantifiers, *in* J. Mycielski et al, ed., 'Structures in Logic and Computer Science', number 1261 *in* 'Lecture notes in computer science', Springer, Berlin, pp. 51–65.

[illegible]

Acknowledgements

[illegible]

References

[illegible]

What's at Stack in Discourse

Stefan Kaufmann, Stanford University[0]

Introduction

This is a paper on modal subordination. I present the idea as an extension of the dynamic logic found in Groenenkijk, Stokhof and Veltman 1996 [2], henceforth referred to as GSV. An information state s is a set of possibilities $i \in I$, where a possibility is a pair of a referent system and a possible world. A referent system is a two-step assignment function: Variables point to *pegs*, unique persistent objects which in turn are assigned to objects in the domain of individuals. This setup makes it possible to keep the number of variables that are active at any point in discourse small: A newly introduced discourse referent is associated with a fresh peg, while the variable referring to that peg may be reassigned ¿from its previous use.

The details of the system are laid out in [2, 185–195]. The definition of *support*, through some intermediate notions, states that a state s supports a proposition ϕ iff the state $s[\phi]$ exists and contains descendants of *all* possibilities in s. A descendant $i\prime$ of a possibility i preserves the possible world of i, and its referent system differs from that of i at most in the introduction of new pegs and the assignment of variables to them.

Temporary Contexts

Consider what it takes to interpret the following well-known example from[2][1]:

(1) a. A wolf might come in.
b. It would eat you first.
c. $\Diamond p;^{\mathrm{w}} q$

The procedure is usually assumed to consist of (i) temporarily adding information to the present state and (ii) examining the outcome. Crucially in cases of modal subordination, the auxiliary state derived in the process is available for the immediately following discourse.

In a brief informal discussion of this kind of procedure, GSV talk about such temporary states as being kept "in memory" or "removed ¿from memory" [2, 204]. This is a nice intuitive metaphor. At the same time it demonstrates the need to think of discourse processing as happening to something bigger than an information state in the usual sense, viz. an environment that has "memory" in which entire states can be stored and retrieved. This also requires a way of distinguishing between and referring to states.

In the above example (1), starting out from an initial state s, the two steps are as follows: First, update s with p, thereby obtaining a state $s\prime$ in which p is supported. Second, examine this new state and check that it is non-empty. Keep the temporary state $s\prime$, which supports p, available for further operations. The interpretation of the next proposition, q, then operates on this temporary state, $s\prime$.

The result of processing (1) is a state in which it is known that

(2) a. a wolf might come in ($\Diamond p$) and
b. *if a wolf comes in*, it eats you first ($p \rightarrow q$)

[0]Thanks to Henriëtte de Swart, Johan van Benthem, Stanley Peters, David Beaver, Ikumi Imani, Hideyuki Nakashima and the people at ETL, Tsukuba.

[1]I use the operator $^{\mathrm{w}}\cdot$ as the translation of *would*.

How does the implication in (2)b come about? The interpreter has derived a temporary state $s\prime$ by applying p. In other words, $s\prime$ is the set of *all* possibilities obtained by updating s with p. Next, the interpreter learns that $s\prime$ supports q. According to the definition of *support* given above, this means that *all* the remaining possibilities in $s\prime$ have descendants in $s\prime[q]$. So the two steps combined result in a state in which is known that *every* possibility in $s[p]$ subsists $s[p][q]$. But this is the definition of implication.

This result provides the intuitive foundation of the treatment proposed here. Processing a modally subordinated statement is a normal update on a temporary state; its interpretation as the consequent of an implication follows from the way the states involved are related.

Returning to the above example of the "main" state s and the auxiliary state $s\prime$, the last piece of information to be applied to s, $[p \rightarrow q]$, is indirectly obtained from a statement about the effect of $[q]$ on $s\prime$. In other words, the information that s supports $p \rightarrow q$ is recovered from the information that $s\prime$ supports q. In general, gaining information in one state through the use of an auxiliary state means learning in the former about the latter.

It will be useful to have a way of talking about this process of learning in one state about another. For this we can capitalize on the conception of propositions as functions from states to states, which makes the relations of implication and support interdefineable: In any given state s, information about a proposition ϕ is information about the state obtained by applying ϕ to s. To know in state s that p implies q means to know that $s[p]$ supports q. To know that $\neg p$ means to know that $s[p]$ is the empty state. And so on.

Conversely, to know in state s that state $s\prime$ supports q means to know that any proposition that, when applied to s, yields $s\prime$, implies q.[2] I use this correlation to extend the formalism (where "$s \vdash \psi$" reads "s supports ψ):

(3) $a[s \vdash \psi]b \Leftrightarrow \forall \phi \big(b[\phi]s \Rightarrow b \vdash (\phi \rightarrow \psi) \big)$

We can start to implement these notions by representing both contexts, the "real" one (which is assumed to contain the "real" world) and the temporarily derived one, in parallel. When (3)a is applied to an initial state s, the second context $s\prime$ is derived as the result of updating s with p. Next, it is asserted that $s\prime$ also supports q. Finally, this results in the update of the original state with $p \rightarrow q$. In short, the processing of (3) should lead through something like the following steps:

(4)

	$\exists s\prime\ s[p]s\prime$	$[q]$
$\exists s\ Init(s)$	$[\Diamond p]$	$([s\prime \models q])$

This eliminates from the original state s those possibilites incompatible with p, and furthermore, from the remaining set of possibilities those are eliminated which do not persist after the application of p and q. The paranthesized operation in the lower right corner of (4) stands for the resulting implication.

Similar effects are observed in other cases. Consider (5) from Roberts [4]:

(5) a. If John bought a book, he'll be home reading it by now.
b. It'll be a murder mystery.
c. $p \rightarrow q;^{\mathbf{w}}r$

Here the condition embedded under *if* in the first sentence should be kept around

[2]For any two states $s, s\prime$, where $s \leq s\prime$ (in the sense of [2, 188]), there is a class of (compositions of) propositions taking s to $s\prime$. Such propositions need not necessarily correspond straightforwardly to natural-language expressions.

for use in interpreting the second. Put in the same tabular form as the previous example, this would lead the interpreter through these steps:

(6)

	$\exists s\prime\ s[p]s\prime$	$[q]$	$[r]$
$\exists s\ Init(s)$		$([s\prime \models q])$	$([s\prime[q] \models r])$

Similarly with negation. Adding to a state s the information that $\neg p$ makes it possible to talk (counterfactually) about what would be the case if p:

(7) a. John doesn't own a Porsche.
b. His wife would hate it.
c. $\neg p;^{w} q$
d.

	$\exists s\prime\ s[p]s\prime$	$[q]$
$\exists s\ Init(s)$	$[\neg p]$	$([s\prime \models q])$

Temporary states are not available across arbitrary stretches of discourse. Switching to plain indicative closes off modal contexts, i.e., any temporary state is abandoned ("removed from memory", in GSV's terms):

(8) a. If John bought a book, he'll be home reading it by now.
b. John works at a gas station.
c. #It'll be a murder mystery.

Finally, the procedure is recursive. From a temporarily derived context, another one can be derived. Consider another continuation of example (1), this time with one more layer of subordination:

(9) a. A wolf might come in.
b. It would eat you first.
c. It might also open the fridge.
d. It would drink the mango juice.

The first temporary state, $s\prime$, however, must be kept and updated. Suppose that (9) is further continued with (10):

(10) a. It might not open the fridge, though.

Here the interpreter should be able to revert to $s\prime$, i.e., abandoning $s\prime\prime$ should not completely throw him out of the modal context.

Stacks

The formal representation I am proposing was already implicit in the tables of the previous section. I assume that processing operates not on states, but on *stacks* of states. In plain indicative mood, the stack has one element and behaves like the usual state; introducing and abandoning temporary contexts corresponds to pushing and popping, respectively.

Definition 1 (Stacks) *A stack σ is a structure $\langle S, < \rangle$, where $S = \{s_1, \dots, s_n\}$ is a set of states ordered by the transitive, non-reflexive and antisymmetric relation $<$. I write (σ, s_n) for the stack consisting of $(s_1, \dots, s_n)$. $\emptyset$ is the empty stack, and (s) is shorthand for $(\emptyset, s)$.*

To refer to operations on such stacks, I introduce a set of operators. The three main ones are for pushing a state ($[\cdot]^{\uparrow}$), making an assertion in a temporary state ($[\cdot]_{\downarrow}$), and popping a state from the stack ($[\bigtriangledown]$). Together with the auxiliary operations $[\cdot]_{\cup}$ and $[\bigtriangledown]!$, these are sufficient for the translation of *if-then* clauses.

Definition 2 (Stack Operations) *The set of stack operators includes the following:*

a.	Assume:	$(\sigma, s)[\phi]^{\uparrow}(\tau, t) \Leftrightarrow \tau = (\sigma, s) \wedge s[\phi]t$
b.	Conclude:	$(\sigma, s)[\phi]_{\downarrow}(\tau, t) \Leftrightarrow \sigma[s \vdash \phi]_{\cup}\tau \wedge s[\phi]t$
c.	Trickle:	$(s)[\phi]_{\cup}(t) \Leftrightarrow s[\phi]t$
		$(\sigma, s)[\phi]_{\cup}(\tau, t) \Leftrightarrow \sigma[\phi]_{\cup}\tau \wedge s[\phi]t$
d.	Pop:	$(\sigma, s)[\nabla]\sigma$
e.	Popout:	$(s)[\nabla]!(s)$
		$\sigma[\nabla]!\tau \Leftrightarrow \sigma[\nabla] \circ [\nabla]!\tau$

The "trickle" operator $[\cdot]_{\cup}$ propagates an assertion down the stack if the stack has several elements. It ensures that the bottom and all intermediate elements are updated.

These operations are triggered by certain linguistic expressions:

Definition 3 (Translations) *A translation* $[\![\cdot]\!]$ *maps linguistic expressions to stack operations:*

a. $[\![p]\!] = [\nabla]! \circ [p]$
b. $[\![\textit{if } p \textit{ then } q]\!] = [p]^{\uparrow} \circ [q]_{\downarrow}$
c. $[\![^{w}p]\!] = [p]_{\downarrow}$

Existential modality and negation require a slightly different operation. Consider negation: What is stated about the temporary state is an assertion not about a property common to all possibilities it contains, but about its cardinality. Let us call this (meta-level) statement "0" and run the definitions as in (11):

(11) a. $s \vdash 0 \Leftrightarrow s = \emptyset$
b. $[\neg p] = [p \rightarrow 0]$
c. $[\![\text{not } p]\!] = [p]^{\uparrow} \circ [0]_{\downarrow}$

Applying the sequence in (11)c to a state s will indeed result in the elimination of those possibilities in s that have descendants in $s[p]$, but it will also render $s[p]$ useless for any further modalized updates.

To avoid this unwelcome result, negation and possibility are processed as in (12)a, and the corresponding linguistic expressions are translated as in (12)b,c:

(12) a. $(\sigma, s)[p]_{\downdownarrows}(\tau, t) \Leftrightarrow t = s \wedge \sigma[s \vdash p]_{\downarrow}\tau$
b. $[\![\text{not } p]\!] = [p]^{\uparrow} \circ [0]_{\downdownarrows}$
c. $[\![\text{might } p]\!] = [p]^{\uparrow} \circ [1]_{\downdownarrows}$

This has the desired effect of leaving the derived context intact for later retrieval.

A sample dialogue

A simple example will illustrate this and show that the discourse method of keeping track of temporary states is not limited to the examples discussed above. Consider the following simple dialogue between Mary and Beth, arriving at Mary's home late at night:

(13) a. M: My husband isn't home yet.
b. B: How do you know?
c. M: Well, the light would be turned on!

Dialogue is aimed at levelling out differences between the knowledge states of its participants. Here, Mary transfers one fact and one rule ¿from her own state to Beth's.

As they approach Mary's home, they can both see that the light is turned off. Let's call this fact $\neg q$. Next, Mary utters (13)a:

(14) "$\neg p$"

Beth is curious to find out how $\neg p$ follows from $\neg q$. So she asks (13)b, repeated as (15)a:

(15) "How does $\neg p$ follow from what we know?"

Mary's reaction makes sense only if we assume that p is available for modal subordination. Her utterance of (13)c, given here as (16)a, is interpreted by Beth as (16)b:

(16) a. "${}^{\mathrm{w}}q$"
b. $p \rightarrow q$
c. $$\frac{\neg q \quad p \rightarrow q}{\neg p}$$

Mary's utterance of $\neg p$ in (13)a makes p available as an antecedent for the implication $p \rightarrow q$, which is the missing link that Beth needed in order to replicate Mary's modus tollens.

In the framework presented here, Mary's two utterances translate into

(17) $[p]^{\uparrow} \circ [0]_{\downarrow\downarrow}; [q]_{\downarrow}$

This provides Beth with exactly the information she needs: $\neg p$ and $p \rightarrow q$.

Referents

The *wolf* example in GVS in fact allows for two interpretations depending on the relative order of the modal and the existential operator associated with the indefinite NP. A specific reading, in which a particular wolf is referred to, is obtained by processing the existential first. Then the animal is available in the original state, say s, and by inheritance also in $s\prime$. On this reading, the discourse in (1) can felicitously be continued with reference to the wolf in the indicative (18):

(18) It looks hungry.

If, however, the order is reversed, then the wolf is present only in the modal context, and the continuation with (18) fails to find an antecedent for the pronoun.

Definites, however, can be introduced in a modal context and remain available. Thus regardless of the position of the existential, the reference in (19) is unproblematic:

(19) a. A wolf might come in.
b. It would eat the pizza$_i$.
c. It$_i$ smells so good.

Such cases of accommodation can be handled by providing different mechanisms at the subsentential level. While an NP of the form *a wolf* is translated into the sequence $[x]; wolf(x)$, which is applied only at the top level of the stack, definites introduce a change to the referent system that is propagated down through the stack: *the pizza* is introduced at every level.

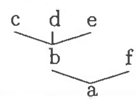
(20) a. indefinites: $[\![\text{a } P]\!] = [x]; P(x)$
b. definites: $[\![\text{the } P]\!] = [[x]; P(x)]_{\cup}$

This is, to be sure, only a rough outline. A related idea using stacks of DRSs can be found in [6].

Further Issues

The stack framework is presented here as a way of handling modal expressions involving quantification over dependent domains. It can be put to other uses as well. This is easy to see when considering its relation to other formalisms, especially trees. A sequence of stacks can alternatively be viewed as a sequence of paths in a tree:

	c	d	e	
(21)	b	b	b	f
	a	a	a	a



In fact, non-accommodational treatments of modal subordination in DRT and its derivatives (cf. [1]) typically build the equivalent of tree structures. However, at any point in a discourse, the stack representation contains no more than one path in the tree. The tree that would correspond to a discourse is therefore not an essential level of representation, but epiphenomenal, showing merely the *history* of the processing.

Furthermore, by virtue of the fact that every newly added piece of information is immediately propagated down the stack, this formalism provides a more realistic picture of the incremental nature of discourse processing than representations in which the result of the processing is available only after some larger structure is completed. This holds also for "Zeinstra's Logic" (cf. [3]), which otherwise has some similarity to this framework.

Other phenomena that can be analyzed in terms of trees would lend themselves to this more dynamic stack treatment. For instance, the interpretation of events with respect to temporal inclusion and precedence has been dealt with in [5] in terms of "Dynamic Aspect Trees". Another application would be quantification in the domain of individuals, rather than worlds. But this is not the right place to pursue these extensions.

References

[1] Anette Frank. *Context Dependence in Modal Constructions.* PhD thesis, IMS, Stuttgart, 1996.

[2] Jeroen Groenendijk, Martin Stokhof, and Frank Veltman. Coreference and modality. In S. Lappin, editor, *The Handbook of Contemporary Semantic Theory*, pages 179–213. Blackwell, Oxford, 1996.

[3] Reinhard Muskens, Johan van Benthem, and Albert Visser. *Dynamics.* Report and Technical Note Series, LP-96-04. ILLC, Amsterdam, 1996.

[4] Craige Roberts. Modal subordination and pronominal anaphora in discourse. *Linguistics and Philosophy*, 12:683–721, 1989.

[5] Alice ter Meulen. *Representing Time in Natural Language.* MIT Press, Cambridge, MA, 1995.

[6] Henk Zeevat. Presupposition and Accommodation in Update Semantics. *Journal of Semantics*, 9:4:379–412, 1992.

On Representationalism in Semantics: A Dynamic Account of *Wh*

Ruth Kempson
SOAS, University of London

Wilfried Meyer Viol
Imperial College, University of London

Dov Gabbay
Imperial College, University of London

The issue over whether there should be any level of representation as part of natural-language semantics has centred on anaphora, where arguments for a representation of weakly specified input replaced by a substituend corresponding to its content have invariably been countered by model-theoretic alternatives. This paper presents *wh* phenomena as an alternative form of evidence. *Wh* expressions are standardly analysed as a variable binding operator, either an n-ary abstraction operator or a form of existential quantifier. Such characterisations lead to the postulation of multiple ambiguities including informative and open questions, mention-some, mention-all, choice, pair-list, functional interpretations (cf. Groenendijk and Stokhof 1997 and references cited there). They leave unexplained the idiosyncratic scopal behaviour of *wh* expressions. On the one hand like indefinites, *wh* expressions display potential for interpretations with scope wider than indicated by their position, but unlike indefinites only relative to some $+Q$ feature as in:

(1) Who told everyone who should concentrate on which topic?

On the other hand, *wh* expressions display potential for narrower scope interpretations than their string-position in so-called functional interpretations:

(2) How many cattle does the EU say every farmer must destroy?

These conflicting signals of relative scope are echoed in those languages which have expletive *wh* forms where from a position supposedly explicitly marking some wide scope potential of a following *wh* expression, the interpretation reportedly triggered is one with the *wh* dependent on a subsequent quantifying expression (Pafel 1996):

(3) Was meint jeder, wo die besten Weine wachsen ?
Where does everyone think the best wines grow?

Variable-binding accounts also do not explain the long-distance dependency effects distinguishing *wh* from other quantifying operators, the distinct distribution of *wh* in situ expressions (requiring analysis as a choice function Reinhart 1997), or the difference between *wh* operators in questions and relatives; and discrete syntactic constraints are set up for various phenomena in the light of this assumption that *wh* is at some level a variable binding operator (subjacency, crossover, resumptive pronouns, expletive *wh*, etc).

In this paper we propose an analysis of *wh* expressions in terms of the dynamics of how utterance interpretation is progressively built up as a tree structure, with *wh* initial expressions defined as projecting a metavariable whose position in the tree may be initially unfixed, and only subsequently identified.[1] The process of interpretation is modelled as a goal-driven, incremental, structure-building operation: the goal is to establish a logical formula of type t by projecting an annotated tree structure reflecting the sub-formulae of this logical form which are then functionally composed through type deduction and other operations. The formulae are

[1]This research was supported by the UK Engineering and Physical Sciences Research Council under grant reference GR/K67397

expressions of the epsilon calculus - arguments of a predicate Fo, with a set of labels which includes a type specification given as argument of a predicate Ty (and other syntactic features): NPs are taken to project variable-binding term-operator expressions of type e. The calculus is extended in two ways. Metavariables are defined which require some discrete formula expression as substituend. And formulae may be labelled with a 'time variable' with an accompanying Te predicate expressing statements about temporal relations. The modal tree logic $LOFT$ for describing tree relations with modal operators $\langle d \rangle$ (the immediate dominance relation), $\langle u \rangle$ (the mother relation), is extended to describe ordered pairs of trees, with a link relation $\langle L \rangle$ between an arbitrary node of a tree and the root of a new tree (cf. Meyer-Viol et al 1997a, 1997b, Kempson et al forthcoming). The full set of operators is $\langle u \rangle$, $\langle d \rangle$, their reflexive transitive closures, $\langle u \rangle^*$, $\langle d \rangle^*$, and the reflexive transitive closures of the union of mother/link and daughter/link relations $\langle U \rangle$, $\langle D \rangle$. With tree descriptions with Kleene star operators we may define tree relations which underspecify any given sequence of node relations. We use such weakly specified tree relations to characterise long-distance dependencies. There is also a locally defined tree-stretching operation for VP adjuncts.

The growth of information accumulated during the interpretation process is defined by a set of inference rules licensing transitions between partial descriptions of trees as individual states relative to a given string pointer and task pointer, each state described in terms of the dynamics of anticipating a node in a tree through requirements on that node as $TODO$ and their subsequent satisfaction as $DONE$. Individual transitions developing tree structure are licensed as long as there is a rule for ensuring compilation of annotations for those nodes.

Sample Inference Rules

(Defined over task states as ordered pairs of $DONE/TODO$ specifications for a given node - $TODO$ specifications on the right of $\bullet$, $DONE$ annotations to its left):[2]

Gap Adjunction

$$\frac{[_{\overline{n}} \bullet Ty(t)]}{[_{\overline{n}} \bullet Ty(t), [_* \bullet Ty(e)]]}$$

Gap Resolution

$$\frac{[_{\overline{m}} [_* Fo(\alpha), Ty(e) \bullet] \ \ldots [_{\overline{n}} \bullet Ty(e)]]}{[_{\overline{m}} \ \ldots [_{\overline{n}} Fo(\alpha), Ty(e) \bullet Ty(e)]]}$$

This pair of rules licenses the introduction of unfixed nodes at nonfinal points in the characterisation, with a process of subsequent identification of a fixed tree position (cf. Meyer-Viol this volume). Gap resolution is restricted to applying when the following input is either empty or will yield an inconsistency with the imposed requirement (for further discussion cf. Kibble this volume).

Link Adjunction

$$\frac{[_n Fo(\langle \mathbf{U}, \beta \rangle), Ty(cn) \bullet]}{[_n Fo(\langle \mathbf{U}, \beta \rangle), Ty(cn) \bullet], [_{nL} \bullet Ty(t), [_* \bullet Fo(\mathbf{U}), Ty(e)]]}$$

Link Completion ($\bullet$ is omissible when the node annotation is complete)

$$\frac{[_0 \ldots [_n Ty(cn), Fo(\langle \mathbf{U}, \beta \rangle)], [_{nL} Ty(t), Fo(\alpha)] \ldots]}{[_0 \ldots [_n Ty(cn), Fo(\langle \mathbf{U}, (\beta \wedge \alpha) \rangle)] \ldots]}$$

[2]Node identifiers are characterised using $\overline{n}$ (an arbitrary sequence of 0,1), $\downarrow$ (daughter), $\uparrow$ (mother), $*$ (any dominance relation) L (Link) and U (any dominance and/or Link relation). Cf Kibble and Meyer-Viol this volume for discussion of tree-node identifiers.

The pair of LINK rules license the introduction of ordered pairs of trees of which the formula of the second, once its tree description is complete, is absorbed into the first. In the formula assigned to common nouns, $Fo(\langle U, \beta \rangle)$, U is a metavariable of type e, β the restrictive predicate provided by the noun. The Link Adjunction rule ensures the transfer of a formula from a node in a tree to a new tree of root node $Tn(\overline{n}L)$ containing a further as yet unfixed node $\langle u \rangle^*(Tn(\overline{n}L))$ required to contain the same formula. So all pairs of linked trees share a common formula. The rule as given is defined for nodes with expressions of type *cn*. In the general case, it might apply to a completed node of any type giving rise to independent ordered pairs of trees.

Interpretation of a string is driven by lexical specifications which given a tree description as trigger project instructions which monotonically update the tree. All content underspecification of an expression is analysed through the assignment of a metavariable resolved by a syntactic substitution process replacing the metavariable with some selected formula of appropriate type. Anaphoric expressions, for example, project metavariables, with locality restrictions determining the structures from which a substituend may/may not be selected. Wellformedness for a sentence-string is defined as the availability of a set of transitions from the axiom and first word to a tree representation of a logical formula with root node of type t, no words remaining and all $TODO$ specifications empty.

It is the dynamics of how tree descriptions monotonically grow across a succession of nodes that provides a typology of *wh* structures and related long-distance dependency effects. Wh initial expressions in questions are defined as annotating a node $\overline{n}$ of type t with the feature $+Q$ and inducing a further node $\langle u \rangle^*(Tn(\overline{n}))$ annotated as $Fo(Wh), Ty(e)$:

$$\frac{[_{\overline{n}} \bullet Ty(t)]}{[_{\overline{n}}\ Lab(+Q),\ [_{*}\ Fo(Wh), Ty(e)]\ \bullet\ Ty(t)]}$$

(Wh is a metavariable; $+Q$ is a feature indicating a propositional formula with at least one Wh metavariable). The variable Wh has a restriction on the choice of substituend: it may not be selected from any node in the same tree. Wh in situ expressions project the formula $Fo(Wh), Ty(e)$ but at a fixed node. The asymmetry between *wh* initial expressions and *wh* in situ expressions, only the former displaying strong island effects follows immediately. The existence of expletive *wh* expressions is also directly allowed for through the dynamics of tree growth and the transfer of specifications from $TODO$ to $DONE$:

(4) Was glaubst du was Hans meint wer Jakob gesehen hat?

(5) Was glaubst du dass Hans meint wer Jakob gesehen hat?

(6) Was glaubst du wer Hans meint dass Jakob gesehen hat?
Who do you think Hans said saw Jakob ?

These anticipatory *wh* expletives are problematic for minimalism accounts (cf. Simpson 1995), at best requiring quite different characterisations for related phenomena in different languages (cf. Lutz & Müller 1996). In HPSG accounts (Johnson & Lappin 1996) *wh* expletives need special stipulation as a discrete form of binding. In the present account, given a common vocabulary for $TODO$ and $DONE$ specifications, weakly specified tree descriptions may occur as a requirement on a node. Expletive *wh* expressions such as German expletive *was* are defined as projecting the weak description given by a full *wh* term as a requirement, thereby inducing the necessity of a full *wh* term at some subsequent point in the construal process to ensure the satisfaction of this requirement:[3]

$$\frac{[_n \bullet Ty(t), [_\downarrow \bullet Ty(e \rightarrow t)]]}{[_n Lab(+Q) \bullet Ty(t), [_\downarrow \bullet Ty(e \rightarrow t), \langle d \rangle^* (Lab(+Q), \langle d \rangle^* Fo(Wh))]]}$$

The restriction *TODO* for the $Ty(e \rightarrow t)$ node directly expresses the requirement of a full form of *wh* expression occurring somewhere lower in the tree.[4] This analysis accounts for a broad array of expletive *was* data including (4)-(10):

(7) *Wer glaubst du was Hans meint dass Jakob gesehen hat?

Who do you think Hans said saw Jacob ?

(8) *Was wer glaubst du dass Jakob gesehen hat?

(9) *Was glaubst er was?

(10) Wer hat gesagt was Hans meint wer Jakob gesehen hat?

Who said who Hans thinks saw Jakob ?

A prediction not shared by alternative analyses of expletive *wh* phenomena is the existence of case-marked expletive forms through further specification of the unfixed node:

(11) Wer glaubst du wer Uli half ?

Who do you think helped Uli ?

These forms require specification of a locally induced complement clause and wer_{expl} can be defined accordingly:[5]

$$\frac{[_{\overline{n}} \bullet Ty(t), [_\downarrow \bullet Ty(e \rightarrow t)]]}{[_{\overline{n}} Lab(+Q) \bullet Ty(t) [_\downarrow \bullet Ty(e \rightarrow t), \langle d \rangle (Lab(+Q), \langle d \rangle^* (Fo(Wh), Ty(e), \langle u \rangle (Ty(t)))))]]}$$

This account explains why with case-marked expletives there should be a sharp drop in acceptability for a sequence of more than two occurrences of the form:

(12) *Wer glaubst du wer Heins meint wer Uli half?

Who do you think Hans said helped Uli?

In dialects where expletive *was*, like wer_{expl}, occurs locally at each clause boundary, it will be defined as having a locally required $+Q$ specification , analogous to wer_{expl}, added to its characterisation as above. Given the requirement by the expletive of three nodes, a *wh* expletive might impose a case requirement on the intermediate node requiring a $+Q$ annotation, yielding an analysis of the Hungarian expletive *mit* which differs from German in that it invariably projects a case requirement on what is projected by its complement clause:

(13) Mit mondtal, hogy kinek vett janos szinhazjegyet?

What-ACC said-2-sg-indef-DO that who-DAT bought Janos-NOM

Who did you say bought Janos a theatre-ticket?

[3]This form is defined as a VP-expletive triggered by a pair of empty nodes, one requiring $Ty(t)$, and its daughter $Ty(e \rightarrow t)$. Such a requirement will trigger the introduction of a pair of daughter nodes from a node with a requirement $Ty(t)$ (cf Meyer-Viol this volume).

[4]There is also a tense restriction to be imposed on the required intermediate node dictating the occurrence of the Te predicate which we do not include here.

[5]We characterise case-marking in terms of position in the tree, the subject position characterised as immediately dominated by a node requiring $Ty(t)$.

$$\frac{[_{\overline{n}} \bullet Ty(t)[_{\downarrow} \bullet Ty(e \to t)]]}{[_{\overline{n}} Lab(+Q) \bullet Ty(t)[_{\downarrow} \bullet Ty(e \to t)[_{\downarrow} \bullet \langle d \rangle^{*}(Lab(+Q), \langle d \rangle^{*} Fo(Wh)), \langle u \rangle (Ty(e \to t))]]]}$$

Or, in a language which licenses in situ *wh* expressions freely, a *wh* expletive might be satisfied by a *wh* expression in situ, as in Iraqi Arabic. In all cases, the analysis depends on the dynamic pairing of a weak description as a requirement on some tree projection for an open Wh metavariable, and its subsequent satisfaction. There is no concept of scope: the closest analogue is the projection of a feature $+Q$ which provides an annotation of which a structural reflex occurs only at a later point in the construal process.

The $TODO/DONE$ dynamics has application also in the analysis of relative clauses as linked trees. The relativising complementiser initiates a linked tree with an unfixed node and a requirement on that node that it be annotated with a copy of the formula of the head nominal. There is variation across languages according to whether such a $TODO$ specification remains as a requirement to be met through anaphora resolution at some fixed node in the tree, or whether the complete annotation of that unfixed node is guaranteed by the relativising complementiser serving an anaphoric role, projecting a Wh variable and replacing it with a copy of the formula inhabiting the head nominal. This, together with variation as to the relative weakness of the tree relation description allows four discrete relative types: the Germanic type with pronominal-like relativising complementiser and an associated gap that displays subjacency effects:

(14) *The paper$_i$ which I respect the journal that rejected e_i is not very good.

the Romance and Arabic types in which a resumptive pronoun is used to construct relative clause construals with/without displaying island effects:

(15) *l'uomo$_i$ che ti parlero solo delle persone che gli$_i$ piacciono .. (Italian)
the man I will talk to you only about the people that to him appeal..

(16) 'am tfattish l-m'allma 'a ktaab ma ?aryu-u ttlamiiz (Arabic colloq)
Asp look.3SF the-teacher for book not read.3P-it the-students
The teacher is looking for a book that the students haven't read it

(17) qara?tu l-maqaalata llatii saafar ash-shaabbu lladhi katab-ha (Arabic cl.)
read-I the-article that travelled the-young man that wrote-it
I read the article that the man who wrote it travelled.

and finally the Japanese type in which an initial expression may be associated with a position internal to a relative clause without further lexical input, yet without giving rise to strong island effects:

(18) ?ano$_i$ [[kawaigatte-ita] inu$_j$-ga [shinde shimatta]] kodomo$_i$-wa kanashinda.
That$_i$ [[pro$_i$ pro$_j$ be fond of] dog$_j$-NOM [ended-up dying]] the child$_i$-TOPIC upset-was
That child of whom the dog of whom he was fond ended up dying was upset.

The four types are distinguished below through the characterisation of the tree $\overline{n}L$ for some nominal $Fo(\langle U, \beta \rangle), Ty(cn)$ at node $\overline{n}$, to which $\overline{n}L$ is linked:

Germanic
$[_{\overline{n}L}[_* \ Fo(Wh/U), Ty(e)] \bullet Ty(t)]$
Italian
$[_{\overline{n}L} \ \bullet Ty(t), [_* \ \bullet Fo(U), Ty(e)]]$
Japanese
$[_{\overline{n}L} \ \bullet Ty(t)], [_{\overline{n}LU} \ Fo(U), Ty(e) \bullet \ ]$
Arabic
$[_{\overline{n}L} \ \bullet Ty(t)], [_{\overline{n}LU} \ \bullet Fo(U), Ty(e)]$

No statement obligatorily inducing resumptive pronouns in languages such as Arabic is needed. Given the imposition of the required common element of linked trees and yet no provision of this element by the complementiser, the only way to satisfy this requirement will be through appropriate choice of value for some pronominal. Anaphora resolution and the fixing of the initially unfixed node thus interact to determine syntactic wellformedness - the structural nature of both processes is essential to expressing this interaction.

The analysis of the interpretation of *wh* questions/relatives has depended on nodes being initially unfixed in a tree, syntactic substitution of a place-holding variable given as an input lexical specification for *wh*, and the dynamics of anticipating/completing incomplete tree descriptions. Its success in correlating questions and relatives on the one hand and relatives and pronouns on the other confirms the need for a level of representation in characterising asymmetries between weak lexical specifications of content and their divergent interpretations in context. However, structures over which the requisite substitution processes are defined to characterise this diversity are also the structures over which long-distance dependency generalisations are expressed. The framework articulates as syntax both a level of structure for which a model-theoretic semantics is definable and the dynamics whereby such a level is incrementally projected: but the result is a mono-level framework for characterising natural language interpretation.

References

Groenendijk,J. & Stokhof,M. 1997. Questions. In van Benthem & ter Meulen, (eds),*Handbook of Logic and Language.* Kluwer.

Johnson, D. & Lappin, S. 1996. *Wh*-questions: unification in a typed feature structure grammar *vs* feature checking in the minimalist program *Proceedings of 12th Annual Conference of Israel Association for Theoretical Linguistics.*

Kempson, R. et al (fcmng)Syntactic Computation as Labelled Deduction, Borsley, R. (ed.) *Syntactic Categories* Academic Press.

Lutz, U. & Müller, G. (eds.) 1996 *Papers on Wh-scope Marking: The Syntax and Semantics of Wh scope marking Workshop.* Stuttgart.

Meyer-Viol, W. et al (1997a) Language Understanding: A Procedural perspective. In Retore, C. (ed.) *Logical Aspects of Computational Linguistics*, LNAI 1328, 228-48. Springer.

Meyer-Viol, W. et al (1997b) Indefinites as epsilon terms *IWCS* Tilburg.

Pafel, H-J. 1996. Absolute and relative: on scope in German *wh* sentences. in Lutz. & Müller (eds.), 231-56.

Reinhart, T. 1997. Quantifier scope: how labor is divided between QR and choice functions. *Linguistics and Philosophy*, 20.4, 335-97.

Simpson, A. 1995. Wh movement, Licensing, Locality of Feature Checking. Ph.D. SOAS.

Incremental interpretation using a tree description language[1]

Rodger Kibble, Lutz Marten, SOAS, University of London
Wilfried Meyer Viol, Imperial College, University of London

This paper briefly reports on the implementation of a variant of the LDS_{NL} framework described by Meyer Viol (this volume) and Kempson et al (this volume) and proceeds to a programmatic discussion of proposed future developments, bringing out some consequences of the methodological goal of *incrementality* combined with the assumption that the single level of representational structure required is a (decorated) binary function-argument tree with a type-logical 'backbone'.

The current system has been implemented in Sicstus Prolog with the following results: (i) translation of natural language input into formulas of the epsilon calculus; (ii) correct predictions for a broad range of 'crossover' data in English questions and relative clauses; (iii) runtime options for interaction of 'gap' construal and pronoun resolution producing consistent results for clear cases and varying results for marginal cases, (such as those involving resumptive pronouns) offering a possible way of modelling between-speaker differences; and (iv) 'incremental' determination of quantifier scope in simple sentences via online choice of term dependencies. The parser is implemented as a state transition system with parse states represented as sequences of unit clauses in the Prolog database[2]. A fuller description appears in (Kibble et al forthcoming).

1. Structure and Context

Steedman 1983 suggested that progress in NLP would come from 'refin[ing] techniques for representing context and focus ... rather than structural parsing techniques'. In fact a focus of recent research has been on techniques for incrementally generating partially specified structural descriptions allowing contextual factors to resolve local ambiguity without the need for re-analysis. In what follows we develop some techniques for building partial trees which provide an interface for knowledge-based inference; development of the inferential system is a separate task which we do not address here. The goal here is to establish what structural operations are needed in order to define an appropriate interface for incorporating contextual information when making parsing decisions. The account incorporates the modal tree logic LOFT (cf Meyer Viol this volume, and references cited there). The system has the following characteristics:

1. Rather than analysing (surface) syntactic structure, we generate 'incrementally' a logical representation consisting of a binary tree whose nodes are decorated with type-logical formulas paired with λ-expressions, with the final logical form derived by successive function application between sister nodes.

2. Use of the tree logic allows fine-tuning with some subtrees rigid within an 'elastic' structure: relations between nodes include $\langle d \rangle$ 'daughter' ($\langle d_0 \rangle$, $\langle d_1 \rangle$ are first and second daughters respectively), $\langle u \rangle$ 'mother' with their reflexive transitive closures $\langle d \rangle *$, $\langle u \rangle *$. So, $\langle d \rangle * \phi$ is read as "ϕ holds at the current node or somewhere below it".

3. Tree nodes are addressed as follows:

a. 0 is a root node address

b. If n is an address, $n0$, $n1$ are daughter nodes of n

c. If n is an address, $n\overline{a}$, $n\overline{b}$ are addresses, where $\overline{a}$ $\overline{b}$ stand for (possibly empty) sequences of binary integers.

[1]This research was supported by the EPSRC under grant reference GR/K67397, 'A Labelled deductive system for natural language understanding'.

[2]It is intended that the Prolog code and supporting documentation will be made available on the Web from January 1998, at the URL `http://semantics.soas.ac.uk/ldsnl/`.

We show trees as labelled bracketed strings $[_{n1}\ \phi\ [_{n2}\ \psi]_{ty2}]_{ty1}$, with $n1\ldots$ the address, $ty1\ldots$ the semantic type.

4. Finally the type-logical notation is extended to allow formulas of the form $a^n \rightarrow b$, where function application may take place up to n times with arguments of type a: $a^1 \rightarrow b$, $a\ /\ b$; $a^n \rightarrow b$, $a\ /\ a^{n-1} \rightarrow b$ if $n > 1$. This allows for verbs to be defined as having a limited number of 'optional arguments' corresponding to thematic roles, with existential closure applying if a derivation completes with $n > 1$.

2. Applications

2.1 Adjuncts

The idea that complements and adjuncts are syntactically identical has recently been discussed in several frameworks; most extensively in HPSG (van Noord and Bouma 1994, Bouma et al 1997.), but also in WG (Kreps 1997). In all these proposals, the conflation of complements and adjuncts has apparently created a mismatch between syntax and semantics, since semantically adjuncts are (still) treated as outlined in e.g. Montague (1974), as a function on predicates (while complements are arguments to predicates).

With respect to syntax-semantics parallelism a more coherent approach is to make complements and adjuncts also semantically as similar as possible; since arguments are difficult to model as functions on predicates (in the framework we adopt), the more obvious move is to treat adjuncts semantically as arguments.

We will not rehearse the linguistic arguments here but see (Marten MS) for further discussion. The following argumentation concerns the methodological principle of incrementality: by defining initially underspecified tree relations we allow for the incorporation of varying numbers of items without perturbation of existing tree structure. This is demonstrated with a simple example where a PP occurs at a point where the initial goal of recognising a sequence of type t has apparently succeeded:

(1) John sings ∘ in the bath.

The ∘ symbol marks the position of the read head, where the string recognised this far is potentially a sentence. The following partial tree allows for further material to be incorporated without deleting any structure:

T1 $[_0\ [_{00}\ \text{John}]_e\ [_{01}\ [_{01a},\ \text{sings}]_{e^n \rightarrow t}\ ]_{e \rightarrow t}]_t$:

sings is at or below the VP node.

Possible completion at this point:

T2 $[_0\ [_{00}\ \text{John}]_e\ [_{01}\ \text{sings}]_{e \rightarrow t}]_t$
a equated to $\emptyset$, n to 1.

However we defer completion until we can be certain there is no more material to incorporate:

john sings in the bath ∘ as above plus:

T3 $[_{01b},\ \langle d_0 \rangle 01a,\ [_{01b1}\ \text{bath},\ +\text{LOC}]_e]_{e^{n-1} \rightarrow t}$:

Node $01b$ is above $01a$ and is at or below the VP node; $01b1$ is a sister of $01a$.
Possible completion at this point:

T4 $[_0\ [_{00}\ \text{John}]_e\ [_{01}\ [_{010}\ \text{sings}]_{e^n \rightarrow t}\ [_{011}\ \text{bath},\ +\text{LOC}]_e]_{e \rightarrow t}]_t$
a equated to 0, b equated to $\emptyset$, n to 2.

2.2 Garden paths:

In certain cases of local ambiguity there is a choice whether to resolve an argument position to a scanned NP or by existential closure. The assumption that this is controlled by a plausibility metric based on domain knowledge accounts for the fact that garden path effects differ between structurally similar sentences with differing content:

(2.) While John was washing the soap got in his eyes.

(3a.) While John was knitting the jumper fell on the floor.
(3b.) While John was knitting the jumper the wool fell on the floor.

In example (3a) the string *While ... jumper* is likely to be initally read as a sentence, and a process of backtracking and argument re-analysis is necessary to make sense of the sentence as a whole. However this difficulty appears to be absent in (2). The difference is that *the jumper* is naturally read as an argument of *knitting* but *the soap* is not likely to be read as the object of *washing*. Assume the following tree structure at **while john was V-ing** ∘

T5 $[_0[_{00}[_{000}$ while$]_{t\to(t\to t)}$
$[_{001}$ $[_{0010}$ john$]_e$ $[_{0011}[_{0011a}$ wash/knit$]$ $_{e^n\to t}$ $]_{e\to t}]_t]_{t\to t}$ $[_{01}$ --$]_t]_t$

The incoming type e phrase initially induces a subtree which remains unfixed pending a decision whether to combine it with the $e^n \to t$ node or to defer attachment:

$[_{0b}$ Fo(soap/jumper)$]_e$
(internal structure suppressed).

In (2) existential closure applies and 0011a is equated with 0011 ($a = \emptyset$), closing the $e \to t$ node:

T6 $[_0[_{00}[_{000}$ while$]_{t\to(t\to t)}$ $[_{001}$ $[_{0010}$ john$]_e$ $[_{0011}$ wash$]_{e\to t}]_t]_{t\to t}$ $[_{01}$ --$]_t]_t$

The remaining string *the soap...* generates a subtree of type t rooted at node 01. In (3) *the jumper* is scanned as an argument of *knit* inducing the following node:

$[_{0011c}$, $\langle d_0\rangle$0011a, $\langle d_1\rangle$0b,$]_{e^{n-1}\to t}$

with the potential completion

T7 $[_0[_{00}[_{000}$ while$]_{t\to(t\to t)}$
$[_{001}$ $[_{0010}$ john$]_e$ $[_{0011}[_{00110}$ knit$]_{e^n\to t}$ $[_{00111}$ jumper$]_e$ $]_{e\to t}]_t]_{t\to t}$ $[_{01}$ --$]_t]_t$

which in (3a) leads to a failed parse; the string *fell on the floor* does not match the requirement for a constituent of type t at 01, in contrast to (3b) where *the jumper* is correctly analysed as an argument of *knit* and *the wool* as initiating a new clause. The fact that (2) may be interpreted 'deterministically' whereas (3a) requires backtracking and re-analysis is intended to model the difference in ease of processing between the two examples.

3. Consequences for the formal system:

Non-linear abstraction: since 'optional arguments' are optional and need not occur in a fixed order, we need to replace the linear sequence of abstracted variables with an unordered set which pairs variables with argument roles:

$$\mathtt{APL}(\lambda(\{x_i \to r_i\} \cup L)\phi, t) = L\phi[t/x_i]$$

where APL stands for function application in the lambda calculus, $L = \{x_1 \to r_1, \ldots x_n \to r_n\}$ (cf Ruhrberg 1996), and the term t is 'suitable' for argument r_i of relation R.

Given unordered abstraction it is important to ensure that the arguments are paired up with the right roles: we don't want e.g. *John loves Mary* to come out as *love(mary,john)*. We may impose a partial ordering corresponding to obliqueness for arguments which fill grammatical roles, as well as requiring arguments to be 'appropriate' for the role they are assigned to.

Optionality: We have not been completely precise about what is meant by 'optional arguments': whether a predicate is taken to denote a relation with a fixed number of arguments which may not be realised in surface structure, or whether a family of relations of varying valences is involved, selected according to the number of argument positions which are instantiated. For the purposes of this paper we assume a 'template semantics' with a finite number of thematic roles lexically specified for each predicate, which will either be filled by linguistic material or resolved by existential closure or by identification with some contextually salient entity. Adjuncts will be assigned roles according to a combination of the preposition (if present) and semantic content. This is not an uncontroversial assumption: one argument in favour is that in general one cannot iterate PPs corresponding to a particular role:

(5) ?#Adam baked a cake for Debbie for Susan

On the other hand, the 'template' approach seems to commit us to the counter-intuitive position that the roles are always (at least implicitly) filled, e.g. that *Adam baked a cake* implies *Adam baked a cake for someone*, which is less plausible then the inference that he baked it *somewhere* or *at some time*.

The most modest interpretation of this proposal is that it models the syntactic behaviour of (PP-)adjuncts in the VP, characterised as being optional in terms of subcategorisation, but behaving identically to complements once they are there. This quasi-syntactic solution for a syntactic problem, however, introduces problems in the semantic representation, since, under a template view the problem of optionality is really only pushed up one level to semantic argument positions. Specific problems include the exact number and charaterisation of the semantic 'roles', their heterogenity (in particular under existential closure), the identification of adjuncts and semantic position (especially since the distinction of PP vs NP is not coextensive with the distinction between adjuncts and complements), and the extension of the proposal to S- and NP-adjunction and to non-PP-adjunction (lexical, derived, sentential adverbs). Nor is it clear as yet what role the 'unmarked order' of thematically distinct adjuncts plays, or how to handle iteration of thematically identical adjuncts.

Abduction: at this point we must acknowledge an apparent stumbling-block in the way of the above account. As the system is set up, we may only check the applicability of a functor to a potential argument if both are attached to sister nodes within a subtree. Yet the precise purpose of the above approach is to do the semantic checking before deciding whether to construct the subtree. If the subtree is created first it may subsequently have to be dismantled, losing incrementality. We propose to tackle this by bringing in *abductive* inference: first we check whether function application succeeds between two *potential* sister nodes, and if it does we introduce the necessary premises.

Take the following instance of the **Elimination** schema:

$$\frac{[_0 \ldots [_{\overline{n}}[_{\overline{n}0} Fo(\lambda(\{r_i \to x\} \cup L)\phi,]_{e^n \to t}, [_{\overline{n}1} Fo(\alpha), \ ]_e \ldots] \ldots \bullet Ty(t)]}{[_0 \ldots [_{\overline{n}} Fo(L\phi[x/\alpha])]_{e^{n-1} \to t} \ldots \bullet Ty(t)]}$$

This essentially states that if a node at $Tn(n)$ immediately dominates a pair of nodes with a lambda abstract and a term in their respective *Done* lists, the result of applying the abstract to the term may be added to *Done* at $Tn(n)$. This can be 'unpacked' as follows (with N_i tree nodes, P, P' parse states):

(i)	$N_1 \in P$	$\{\mathrm{Fo}(\lambda(\{r_i \to x\} \cup L)\phi,\ \mathrm{Ty}(e^n \to t) \bullet 0\}$
(ii)	$N_2 \in P$	$\{\mathrm{Fo}(\alpha),\ \mathrm{Ty}(e) \bullet 0\}$
(iii)		$\mathtt{APL}(\lambda(\{x \to r_i\} \cup L)\phi, \alpha) = L\phi[\alpha/x]$
(iv)	$N_3 \in P$	$\{\langle d\rangle N_1,\ \langle d\rangle N_2 \bullet 0\}$
(v)	$N_3 \in P'$	$\{Fo(L\phi[\alpha/x]),\ \mathrm{Ty}(e^{n-1} \to t\ )\bullet 0\}$

Side condition on (iii): term α 'appropriate' for role r_1.

In the configuration shown in **T5**, one thing which is missing is a node corresponding to N_3 (line iv). That is, there is no node which is shown as immediately dominating both the functor and argument nodes. By 'abducing' this node, assuming lines (i-iii) hold (in the case of *knit* and *jumper*) a transition is licensed to the parse state shown in **T7**. In the case of *wash* and *soap* the application at line (iii) will fail (*soap* is not an appropriate DO of *wash*) and so we do not proceed to introduce N_3, but keep the *e*-node unfixed until we find another location for it.

Long Distance Dependencies: the modifications proposed here have implications for the account of *Wh*-gap resolution outlined by Kempson et al (this volume) since optionality of arguments has the consequence that we cannot rely on structural factors and semantic typing alone to trigger the Gap Resolution rule. Compare examples (6) and (7) which are isomorphic with regard to surface structure:

(6) The house where Karl Marx was born in Trier ...

this can only mean 'the house in Trier where KM was born' not 'the house s.t. KM was born in Trier in that house'; only one adjunct may fill the 'Location' role. On the other hand:

(7) The house where Marx wrote the Communist Manifesto in the kitchen ...

means 'the house s.t. KM wrote the Communist Manifesto in the kitchen in that house'. The difference here is that the Location role in the relative clause may be filled by a combination of *the house* and *the kitchen* since there is a relation of *inclusion*. These examples suggest that rather than gap-resolution being straightforwardly triggered by an inconsistency in the input string, it is actually driven by the availability of an unfixed node which is looking for a 'landing site', and the choice of resolution site is partly determined by considerations of domain knowledge and plausibility. Examples (8a/b) suggest that these factors are involved in the resolution of *wh*-gaps with so-called 'ditransitive' verbs:

(8a.) What did John give Mary *e*?
(8b.) Who did John give *e* a book?

The correct interpretation of these sentences requires the lexical entry for *give* to encode the information that the recipient is normally a person (or an entity with some of the attributes of a person such as an animal or a corporation). In processing (8b) the system will initially attempt to resolve *a book* as recipient (by applying APL as in the Elimination sub-proof shown above) since it is the first overt NP following the verb. Assuming that function application fails on grounds of plausibilty, the unfixed node generated by *Who* will instead be selected to fill this argument position. Unfortunately the situation is complicated by cases like (8c) where *the book* is meant as the 'gift' with the recipient role realised as a PP.

(8c.) Who did John give a book $\circ$ to *e*?

The strategy we have briefly outlined would initially return an incorrect reading for this sentence, necessitating backtracking and re-analysis. What is needed is experimental and/or corpus-based evidence to show whether there is a genuine preference for the order in which arguments are expressed in questions and relative clauses, and whether for instance stylistic preferences such as avoidance of dangling prepositions have any appreciable effect.

4. Concluding remarks

We have indicated various techniques for defining partial tree descriptions in the course of a parse, in a way which allows resolution of local ambiguity to be deferred. We have argued that a common mechanism enables us to handle cases of adjunct attachment and argument re-analysis 'incrementally' on the assumption that these decisions may be determined by non-monotonic reasoning based on contextual knowledge. The ability to create partially specified trees afforded by the tree logic LOFT and the addressing mechanism described in section 1 is an important factor in defining an interface which allows non-deterministic choices to be made on the basis of domain knowledge. In the process we have identified certain areas which require further research: the precise implications for semantic interpretation of postulating predicates with a varying number of arguments; the form in which *domain knowledge* should be represented and the nature of the inference mechanism (e.g. 'weighted abduction', cf Hobbs et al 1993). Finally, more work needs to be done to determine the precise implications for long-distance dependencies of extending the use of structural underspecification to handle optional arguments.

References

Bouma, G., R. Malouf and I. Sag, 1997, Satisfying Constraints on Extraction and Adjunction, MS., Stanford University.

Hobbs, Stickel, Appelt and Martin, 1993, Interpretation as Abduction, *Artificial Intelligence 63*, reprinted in Pereira and Grosz (eds), 1994, *Natural Language Processing*, MIT/Elsevier.

Kempson et al, this volume, On Representationalism in Semantics: A Dynamic Account of *Wh*.

Kibble, R, R Kempson and W Meyer Viol, forthcoming, Implementing LDS_{NL}: Strategies for Pronoun and Wh-Gap Resolution, to appear in *SOAS Working Papers in Linguistics and Phonetics 7*.

van Noord and Bouma 1994, The scope of adjuncts and the processing of lexical rules, *COLING 15*.

Marten, L., MS, Extending Underspecification to Types, Dept of Linguistics, SOAS, London.

Meyer Viol, W, this volume, Parsing as Tree Construction.

Montague, R., 1974, English as a Formal Language, in Thomason (ed), *Formal Philosophy*.

Ruhrberg, P., 1996, A simultaneous abstraction calculus and theories of semantics, in Seligman and Westerstahl (eds), *Logic Language and Computation vol 1*, CSLI

Steedman, M., 1983, Natural and unnatural language processing, in Sparck Jones & Wilks (eds), *Automatic Natural Language Parsing*, Wiley.

Partial Matches and the Interpretation of Anaphoric Noun Phrases[1]

Emiel Krahmer & Kees van Deemter
IPO, Eindhoven *ITRI, Brighton*

1 Introduction

In this paper we will work towards a general theory of context dependent Noun Phrase (NP) meaning. Our starting point is the following hypothesis:

> *Hypothesis 1*: NPs of *all* kinds can depend on linguistic context for their interpretation.

Theories of anaphora can be used to explain the nature of the dependency. Various authors have pointed out that there is an analogy between anaphors and presuppositions (e.g., Van der Sandt 1992). We take it that 'presupposition-hood', and more specifically the mechanism which determines whether a presupposition is projected or cancelled, are important factors related to *hypothesis 1*, and this is reflected by the following hypothesis (to be made more precise below).

> *Hypothesis 2*: All NPs with a *stròng* or *accented* determiner trigger an existence presupposition.

To build a sensible theory on such general assumptions, a number of hurdles have to be taken. To begin with, the anaphoric dependency relation that can be seen to hold between two NPs is by no means unrestricted; in certain cases an anaphoric relation between a would-be anaphor and a would-be antecedent is impossible due to independent constraints. Another factor which complicates the anaphoric dependency relation is that there often is a 'partial match' between an anaphor and its potential antecedent. An example is (1).

(1) If John buys a Siamese cat, his pet won't be happy.

The possessive description 'his pet' triggers the presupposition that John has a pet. This example displays an ambiguity between two readings, depending on whether 'his pet' refers to the Siamese cat (in which case the presupposition is *cancelled*), or not (the presupposition is *projected*). The two readings may be paraphrased as 'If John buys a_i Siamese cat, it_i won't be happy' and 'John has a_j pet and if he buys a Siamese cat, it_j won't be happy'.

A natural starting point for our enterprise is the 'presuppositions as anaphors' approach of Van der Sandt (1992), which not only trades on the assumption that presuppositions and anaphors have much in common, but is also the empirically most adequate theory of presuppositions today. Unfortunately, the theory also has a number of deficiencies for our purposes, in particular where the treatment of partial matches is concerned. If we take a look at Van der Sandt's theory, it turns out that the ambiguity of (1) is not actually predicted by his algorithm and, moreover, that some of the interpretations predicted by it are incorrect. Therefore our current programme is as follows. First we present a modification of the 'presuppositions as anaphors' approach. Then we give an extension of the approach which applies in a uniform way to NPs of all syntactic categories. Finally, we discuss a number of restricting factors on the anaphoric dependency relation having to do with intonation and informativity.

[1] We would like to thank David Beaver, Bart Geurts, Paul Piwek and Rob van der Sandt for comments on earlier versions of this paper.

2 Modifications

The core idea of Van der Sandt (1992) is that in many ways presuppositions behave as anaphors. More concretely, Van der Sandt argues that presuppositions should be resolved just like anaphoric pronouns are resolved in Discourse Representation Theory (DRT, see Kamp & Reyle 1993). Van der Sandt extends the DRT language with *presuppositional* Discourse Representation Structures (DRSs). Before the main DRS of a sentence can be interpreted in the standard way, all presuppositional DRSs contained in the main DRS have to be resolved, and for this purpose Van der Sandt developed a presupposition resolution algorithm. For each presuppositional DRS, the algorithm first looks for an antecedent, and if it finds one the presupposition is *bound* to this antecedent. Binding a presupposition amounts to removing it from its origin (the 'source DRS') and moving it to the site of the newly found antecedent (the 'target DRS'). A difference between presuppositions and pronouns is that when no antecedent for a presupposition can be found, and the presupposition has sufficient descriptive content, the presupposition can be *accommodated*. Accommodating a presupposition amounts to removing the presuppositional DRS from the source DRS and merging it with the main DRS, provided that a number of independently motivated constraints (informativity, consistency) are satisfied. For more details the reader is referred to Van der Sandt (1992).

The algorithm of Van der Sandt is constructed in such a way that binding a presupposition is always preferred to accommodating it. This leads to problems when it is intuitively *possible* to bind a presupposition, but not *necessary*. A case in point are the aforementioned partial matches. Consider:

(2) If John talks to some partygoers, the children will laugh at him.

The theory of Van der Sandt (1992) predicts that (2) has a preferred (binding) interpretation that can be glossed as 'If John talks to some partygoing children, they'll laugh at him.' But this is wrong for two reasons: (*i*) example (2) is ambiguous between a binding and an accommodation reading, and (*ii*) the binding reading (according to which the antecedent clause requires that John talks with individuals who are both partygoers and children) is no valid reading.

To solve these problems we have modified the presupposition resolution algorithm. Here we will give an informal sketch of the algorithm, formal details and worked examples can be found in Krahmer & Van Deemter (1997). On our approach, the initial DRS for example (2) involves, among other things, a dynamic quantification, or *duplex condition* (see Kamp & Reyle 1993), that may informally be rendered as '*The* ($children^C$, *laugh-at-John*)', where C is a specially marked discourse referent acting as a *context variable* (Westerståhl 1985) and where $children^C$ denotes the intersection of C with the set of children. This duplex condition is associated with the following presuppositional DRS:

Z, C
$child^C(Z)$

In words: there is a nonempty set of children, and each of these children is an element of the denotation of C. Our algorithm explicitly operates on the C marker. It can be 'resolved' in two different ways: by equating it to (a contextually salient subset of) the domain of discourse, or to some antecedent.

This raises a question: what *qualifies* as an antecedent? The answer of Van der Sandt (1992) is simple: every suitable discourse referent which is accessible from the DRS containing the presuppositional DRS is a potential antecedent. Van der Sandt does not specify what makes a referent suitable. In our opinion, the main factor in determining the suitability of a discourse referent is the denotation of the descriptive content of the phrase which lead to the introduction of the referent in the first place. Compare:

(3) a. Yesterday, an_1 uncle of mine bumped into a_2 man. The_i man fell to the ground.

b. Yesterday, a_2 man bumped into an_1 uncle of mine. The_i man fell to the ground.

We contend that in both (3.a) and (3.b), the definite *the man* is strongly preferred to be coindexed with *a man* (i.e., $i = 2$), even though obviously both 1 and 2 are male persons. This is due to the fact that 2 is introduced as a *man*, while 1 is introduced as an *uncle*. We therefore take an antecedent to be a tuple, consisting of a discourse referent and a *value set*, that is: the denotation of the phrase which led to the introduction of the referent.

The modified algorithm classifies the relation between an anaphor and a potential antecedent as a full match when the respective value sets are the same in all models. When the respective value sets are disjoint in all models, there is a mismatch. In all other cases, the relation is classified as a partial match. It should be noted that the algorithm operates on *hearer-models*. A hearer-model is a standard first-order model which is in accordance with the hearer's background knowledge. If we apply our modified algorithm to example (2), the algorithm will try to resolve the presupposition triggered by 'the children'. There are two accessible antecedents for this presupposition, 'John' and 'some partygoers', of which the former is not qualified on independent grounds. The algorithm checks the nature of the relationship between the denotations of anaphor (*children*) and a potential antecedent (*partygoers*). Since there will be models in which not all children are partygoers, and models in which not all partygoers are children, the relation between the two is a partial match. When a partial match between an anaphor and a potential antecedent is detected, our algorithm produces two output readings: a binding and an accommodation reading. In the case of (2) the accommodation reading can be glossed as 'There is a_i (contextually salient) group of children, and if John talks to some partygoers, $they_i$ will laugh at him'. The binding reading can be paraphrased as 'If John talks to $some_i$ partygoers, the children among $them_i$ will laugh at him'. Notice that the presupposition triggered by 'the children' is not moved to the antecedent, but is bound *in situ* (in the consequent).

Summarizing, our version of Van der Sandt's (1992) presupposition resolution algorithm differs from the original in three respects: (*i*) it is more explicit in what counts as a potential antecedent (namely a pair consisting of a discourse referent and a value set), (*ii*) it is more explicit about the relation between presupposition and potential antecedent, explicitly distinguishing full match, mismatch and partial match, and generating the required ambiguity in the latter case, and (*iii*) binding is a different operation, defined using contextual quantification: it generalizes to non-identity cases and the presuppositional DRS remains in the DRS where it originated.

3 Extensions

In an extension of Van der Sandt's framework, we argue that the approach can be applied in a uniform way to NPs of all syntactic categories. Thus, not only to definites,[2] but also to indefinites and quantificational NPs. As mentioned in *hypothesis 2* above, an NP can trigger a presupposition in two cases, namely when the determiner is *strong*, or *weak* but accented. More precisely:

[2]For details on how pronouns and proper names, as well as epithets and bridging descriptions (using the approach of Krahmer & Piwek t.a.) fit in the current perspective the reader is referred to Krahmer & van Deemter (1997).

NP PRESUPPOSITION SCHEME
Suppose an NP is of the form [DET CN] and C is some context variable.
If DET is strong or accented, then the NP triggers the presupposition that the intersection of the respective denotations of C and CN is not empty.

The distinction between *strong* and *weak* determiners is due to Milsark (1977), and is based on the observation that the latter, but not the former, can occur in postverbal position in *there* sentences. Thus, 'most' and 'the' are strong determiners, while 'some' and 'no' are weak as illustrated by 'There are {*most / *the / some /no} semanticists at this conference'. De Jong (1987:276), among others, has argued that *all* strong NPs are presupposition triggers. Occasionally, weak NPs can also trigger an existence presupposition, namely when the determiner is accented (Van der Sandt p.c.). Consider (small caps indicate stress):

(4) If a new teacher is hired, then NO/FEW girls in this class immediately have a crush on him. They are primarily interested in the Backstreet Boys.

Accenting the weak determiners 'no' or 'few' triggers a presupposition that there are girls in this class. Our modified algorithm predicts that this presupposition is globally accommodated, thereby creating an antecedent for *they* in the second sentence. Note that NPs with a determiner that is either strong or accented (or both) can give rise to the expected partial match ambiguities.

(5) If the new teacher lectures some pupils, {a. most/b. at least THREE} girls immediately have a crush on him.

The respective DRSs for (5.a) and (5.b) are structurally similar: both have a presuppositional DRS in the consequent presupposing the existence of girls. There are two potential antecedents for this presupposition in the antecedent DRS, of which the new teacher is ruled out on the basis of number. If we assume that there is no relevant hearer knowledge, then there will not be a full match between *girls* and *pupils*. However, there will be a hearer-model M in which the respective denotations of *girl* and *pupil* have a non-empty intersection. In other words: our modified algorithm predicts that the examples in (5) display a partial match, and a genuine ambiguity between a binding and an accommodation reading is predicted, which accords well with our intuitions.

4 Restrictions: Accenting and Informativity

We discuss two factors which put restrictions on the dependency relation: intonation —in particular, pitch accents and the lack thereof— and informativity.

To begin with the former: (de-)accenting puts constraints on both the anaphoric dependency relation and on the ambiguities arising due to partial matches. To simplify, identity anaphors tend to be deaccented, while all other noun phrases must be accented (cf. Van Deemter 1994). Hence, accenting can sometimes have a disambiguating function. For example, the lack of an accent on 'children' in (2) signifies that *all* the partygoers are children, whereas an accent on 'children' signifies that the children are either a real subset of the set of partygoers or some other set of children – but not the entire set of partygoers that John talks to. In other words: de-accenting 'children' in (2) disambiguates this example in favor of the binding interpretation. Accenting 'children' does not fully disambiguate however; it only rules out identity binding.

That *informativity* plays an important role is already acknowledged by Van der Sandt, who uses a Stalnakerian notion of informativity on accommodation: informally, the result of accommodating a presupposition may never lead to an uninformative, or redundant, (sub-)DRS. However, in our opinion, informativity also plays a role below the DRS level. Above we claimed that there is a partial match between an anaphoric phrase and a would-be antecedent if their respective value sets have a non-empty intersection in at least one of the hearer-models. This means that examples in which the anaphor is more informative than a potential antecedent count as a partial match. However, such examples do not always display a partial match ambiguity. Consider the following example:

(6) If John owns a donkey, he thinks that the purple, farmer-eating donkey is on the loose. (After Beaver 1995:114)

Obviously, the binding reading of this example is infelicitous. We think this is due to the following, general constraint (after Krahmer 1995:165).

> INFORMATIVE ANAPHORS HYPOTHESIS (IAH)
> A potential antecedent with a non-specific interpretation, which is less informative than the anaphor under consideration, does not qualify as a *suitable* antecedent for the anaphor, provided that the relation between anaphor and potential antecedent is one of identity.

Thus: an (identity) anaphor can only *add* information about its antecedent when the antecedent has a specific interpretation, and this would account for the fact that the example in (6) defies categorization as a partial match.

Two other issues are closely related with the restrictions on anaphoric relations that have been mentioned so far. The first one is concerned with indefinite NPs. Consider (7), where the second occurrence of 'two men' cannot be anaphoric to its first occurrence:

(7) I saw two men throwing chairs at each other. Two men were drunk.

This exemplifies the following weakening of the well-known Novelty Constraint:

> NONIDENTITY CONSTRAINT
> Indefinite NPs cannot have identity anaphora.

As has been shown in Van Deemter (1992), this constraint can be seen to follow from independent principles: whenever an indefinite and a definite NP are semantically interchangeable (as is the case with the NPs 'two men' and 'the two men' when they quantify over a domain that contains exactly two men) the definite NP is strongly preferred on pragmatic grounds. As a result, when the indefinite is used, there is an implicature to the effect that the definite (which, in the case of (7), would be an identity anaphor) could not have been used.[3] In the case of (7) this implicature is false. The last of the constraints that we will discuss is of a similarly Gricean nature. Consider (8).

(8) A couple of first graders received free lunch packages.
a. Some of the children found this strange.
b. Some of the children in the school found this strange.

While (8.a) is ambiguous between a binding and an accommodation reading, (8.b) only seems to have the accommodation reading; the reading in which 'the children in

[3] E.g., if one would say, 'Yesterday a pope delivered a speech', (rather than 'Yesterday the pope delivered a speech') the implicature would be that there are at least two popes.

the school' ranges over first graders is not present. (Intuitively, the addition 'in the school' serves to 'widen' the domain of discourse.) Yet, semantically speaking, the addition 'in the school' does not preclude an interpretation in which 'the children in the school' quantifies over first graders. We explain the unavailability of the binding reading by appealing to the fact that this interpretation would cause the addition 'in the school' to become uninformative, thus violating the Gricean maxim of Manner.

Let us take stock. Our approach rests on the assumption that every NP can be dependent on the linguistic context for its interpretation. We have seen that the context dependency is subject to various constraints, of which we paid special attention to intonation and informativity. One striking feature is that informativity appears to play such a crucial role. Notice that this is a *different* kind of informativity than the one in Van der Sandt's informativity condition, which applies at the level of DRSs. The observations made above point in the direction of a general informativity constraint on the level of 'value sets', that is: the 'informative weigth' of the anaphor, possibly in combination with the 'informative weigth' of the antecedent. We expect that such a general condition would subsume the informativity-related constraints mentioned above, as well as other limiting conditions. For example, it has been claimed that pronouns trigger a presupposition which is so 'light-weight' that it cannot be accommodated. In our opinion, the same mechanism should apply to descriptions with very little content ('the man'). Again, informativity seems to play a role (when is a presupposition sufficiently informative to be 'accommodatable'?). It will be interesting to see where these (informativity related) constraints on the anaphoric relation will leave the hypotheses mentioned at the outset of this paper, and especially *Hypothesis 1*, in which the notion of anaphora is tentatively generalized so as to apply to the entire domain of noun phrases.

References

[1] Beaver, D. (1995). *Presupposition and Assertion in Dynamic Semantics*, Ph.D. thesis, Edinburgh

[2] Van Deemter, K. (1992). Towards a Generalization of Anaphora. In: *Journal of Semantics* **9**: 27-51

[3] Van Deemter, K. (1994). What's new? A Semantic Perspective on Sentence Accent. In: *Journal of Semantics* **11**: 1-31

[4] De Jong, F. (1987). The compositional nature of (in)definiteness. In: E. Reuland & A. ter Meulen (eds.) *The representation of (in)definiteness.* MIT Press, Cambridge, MA, 270-285

[5] Kamp, H. & U. Reyle (1993). *From Discourse to Logic*, Kluwer Academic Publishers, Dordrecht

[6] Krahmer, E. (1995). *Discourse and Presupposition*, PhD-dissertation, Tilburg.

[7] Krahmer, E. & K. van Deemter (1997). Presuppositions as Anaphors: Towards a Full Understanding of Partial Matches. In: P. Dekker, J. van der Does and H. de Hoop (eds.) *Proceedings of the Groningen Workshop on Definites*, OTS.[4]

[8] Krahmer, E. & P. Piwek (to appear). Presupposition Projection as Proof Construction. In: H. Bunt & R. Muskens (eds.), *Computing Meanings*, Kluwer.

[9] Milsark, G. (1977). Towards an explanation of certain peculiarities in the existential construction in english. *Linguistic Analysis*, 3:1-30

[10] Van der Sandt, R. (1992). Presupposition Projection as Anaphora Resolution, *Journal of Semantics*, **9**, 333-377

[11] Westerståhl, D. (1985), 'Determiners and context sets', in: J. van Benthem & A. ter Meulen (eds), *Generalized quantifiers in natural language*, Foris, Dordrecht

[4] WWW: `http://www.itri.brighton.ac.uk/ Kees.van.Deemter/#papers`.

LOGICAL GRAMMAR WITH DEPENDENCIES AS CATEGORIES

-extended abstract-

Geert-Jan M. Kruijff

Abstract. The major part of the paper discusses a multimodal logical grammar in which dependency relations are used as basic categories. This logical grammar is being developed with the aim to provide an analytic perspective to the Praguian functional description of language. In the final part of the paper the application to word order is discussed, particularly *deep word order* regarding modifiers and heads. It is argued that the deep word order provides structural indications of informativity. The paper concludes with discussing how such indications can be inferred, and how the Praguian notions of topic and focus relate to these indications.

1. Introduction

The Prague School of Linguistics has a long standing as a tradition in the description of natural language. With the inception of the Prague Linguistic Circle in the early 1920s started an approach to perceiving language in a structural/functional way - a perspective which found a mathematical formulation in Sgall et al's Functional Generative Description (FGD; [6]), recently partly reworked by Petkevič where it concerned the relation between deep structure and surface form ([5]).

FGD is a *generative, stratificational* approach in the sense that it shows how different layers of language (for example deep structure, morphology, phonetics) interact with another *for a speaker to formulate an utterance.* The functionalist perspective shows itself in the interaction between layers: A function at one layer is realized by a form at a next layer. Perhaps the most prominent aspect of the approach is that it takes a dependency-based perspective on the description of sentential structure. Thus, we talk of heads, and modifiers *expanding* heads *by specific dependency relations.* It is particularly the use of dependency relations that makes the approach dependency-based, not -merely- the recognition of a head/modifier-asymmetry.

What we would like to pursue here is the development of (the *basics* of) a logical grammar which is based on FGD not only in the sense that it outputs the kind of structures in terms of which FGD describes natural language, but which also attempts to mirror FGD in the *way* a sentence is analysed (see also [2]).

2. Tectogrammatical Representations

The structures we are interested in are *tectogrammatical representations.* A sentence's ('underlying' or 'deep') tectogrammatical representation elucidates how the strings of that sentence can be interpreted as playing specific roles or 'functions' (=linguistic meaning). Within a TR, several dimensions of linguistic meaning are expressed for the entities making up the representation (cf. [5]): Dependency relations, contextual boundness (CB) or nonboundness (NB), deep word order, coordination and apposition (if applicable), and grammatical coreference. We discuss the former three dimensions.

The main structure of the TR arises from how the various elements are related to one another via *dependency relations.* In such a relation, one element (a *modifier*) is said to *expand* another element (the *head*) via a specific kind of dependency relation. Because heads can be expanded by multiple modifiers, whereas a modifier can only be related to one head, a TR can also be depicted as an n-branching tree structure called a *dependency tree*.

We know how words can combine from their lexical entries. The lexical entry for a word provides its *valency frame* that specifies by which dependency relations a word can be expanded. It is possible that the valency frame is empty; if it is not, then for each dependency relation it is specified whether it is obligatory or optional, and whether a dependency relation is an inner participant or a free modifier[1].

Regarding the word's wordclass, we have to make a distinction between words that *do* get represented in a TR, and those that *don't*. Those words that do get represented have one of the following wordclasses: Verb (v), Noun (n), Adjective (*adj*), Adverb (*adv*) or Pronoun (*pro*). These words are also called *auto-semantic*. Yet, there are also words in the sentence which do *not* get represented in the sentence's TR. Among these are *function words* and *auxiliary verbs*. Function words, like prepositions, can be perceived of as means to realize dependency relations. Therefore, resulting from the distinction between deep structure and realization as a surface form, function words and auxiliary verbs are not represented.

Contextual boundness and nonboundness are primary linguistic notions used to classify elements in a tectogrammatical representation as reflecting a speaker's disposition towards the actual state of affairs talked about, and his efforts to accommodate the hearer's needs as to be able to interpret what the speaker intents to convey (cf. [6], p.177). Thereby, contextual boundness can loosely be compared to indicate what is salient, 'given', recoverable from the already established discourse context; whereas contextual nonboundness is similar to 'novelty', not indicating a reference to something established but signalling the *introduction* something new into the context, or the *modification* of something recoverable.

Whether an element of the tectogrammatical representation is CB or NB depends on the actual placement of the modifier relative to the head, and other modifiers of that head. More specifically, we can define for each language a standard ordering in which modifiers (dependency relations) are to be arranged - the *systemic ordering*. The systemic ordering is a total ordering over all possible dependency relations, and is also reflected in a valency frame: For all dependencies D_i, D_j in that valency frame, it holds that $D_i \prec_{so} D_j$ implies that D_i preceeds D_j. Now, roughly put, whenever a modifier occurs in a position different from the position in the systemic ordering, it is judged CB; otherwise, if the position complies with the systemic ordering, it is judged NB. In the tectogrammatical representation we note what elements are CB or NB by simply labelling them as such.

3. Dependency-Based Logical Grammar

Multi-modal logical grammar (MMLG) is a kind of logical grammar in which sensitivity to structure is built in grammatical composition by the use of *modes* ([3, 1] and work by Morrill). These modes are essentially different ways in which elements can be combined together in the process of grammatical composition. Each mode has a distinct logical behavior, licensing structural relaxations or enforcing constraints on how elements can combine. We can control the access to such a mode by means of proper indications (*decorations*) in the lexicon, and by specifying in a rules defining the logical behavior of a particular mode what decorations elements need to have for this rules to be "accessible". We thus obtain a grammar in which various ways of grammatical composition are available - whereby each way could be made available only in situations that would be proper. We use MMLG to

[1] An inner participant: a dependency relation via which a head can only be expanded at most once: free modifiers allow for expansion any finite number of times. Obligatory dependencies require expansion.

model composition in the surface and deep dimensions, and structural sensitivity wrt. functionality.

3.1. **Dependencies as Categories.** Fundamental about our logical grammar is that we use dependency relations and simple wordclasses as our basic categories (since we want to model -a part of- FGD). Traditionally in categorial grammar a constituency-based approach is taken, with the aim of constructing *phrases.* Going to a dependency-based perspective, we do retain some of the standard basic categories (those corresponding to word classes, like n, and the s for a sentence). It is rather the perspective on 'combination' that points out the difference. Whereas in a constituency-based approach one attempts to construct phrases, mostly in a concatenative fashion (*wrapping*-operations being possible in some cases), we try here to combine strings into larger strings that can be interpreted as performing the function of *head* or of *modifier* extending a head by a particular *dependency relation.* Thereby the formation of strings that are *functionally interpretable* is performed at the level of the surface form, whereas roles like head and modifier are played at the level of the deep structure. Because of this separation between strings at the surface form and the function they perform in the deep structure, there is -potentially- more freedom in regarding the order in which the strings have to occur at the surface (concatenation requiring a rather fixed order).

3.2. **A Basic Dependency-Based Logical Grammar - DBLG.** The model theory of DBLG is split up into parts describing the structures of the individual dimensions, and a part describing the semantics of 'interdimensional travel'[2].

The structures we are interested in as for the surface dimension are primarily those that describe a string (a word, or a group of words) -possibly- built by concatenation. In that sense, this model theory is practically like that for NL, modeling pure residuation [3]. The only "extension" is that we allow for the requirement that a particular string is to be interpreted as modifying a head by a specific dependency relation. For example, if we take a preposition "in", then the category we give it is $(n/_s n)\backslash_F$ *Location* - that is, it needs a noun to combine with (by the surface mode-of-combination s) to result in a noun, which requires then to be *functionally interpreted as* $(\backslash_F)$ a modifier expanding the head by a *Location* relation.

The model theory for the deep dimension describes the structures analogous to FGD's tectogrammatical representations. Because composition in this dimension essentially means trying to combine heads and modifiers, a pivotal role is played by categories specifying (the formal equivalent of) valency frames. The fundamental mode is called τ, which is an n-ary product enabling us to specify a category for a head as a list of "left"-modifiers, the head's wordclass, and a list of "right" modifiers (cf. [3]). For instance, a (simplified) for a verb could be $\{(Actor/_F n)\}\backslash_\tau\ s\ /_\tau\{(Patient/_F n)\}$. The category says that the verb needs an Actor and a Patient, to result in a category s. Thereby, the Actor and the Patient both need to be *functionally realized* as a surface string of category n. Furthermore, our structures can contain decorations indicating IP/FM and OBL/OPT - we use ϕ, ω, ψ for obligatory free modifier, optional inner participant, and optional free modifier, respectively.

Finally, let us get back to the mode F that enables us to travel back and forth between the surface and deep dimensions. The difference between this mode and any other modes of composition is that F is *multi*-dimensional because it *relates* the two dimensions. Consequently, its semantics need to be defined in relation *to* both dimensions.

[2]See [2] for the entire elaboration of the model theory in terms of frame semantics.

We should note that, due to its *inter*-dimensional nature, it is more difficult to interpret F as a mode expressing grammatical composition. Because, what it primarily does is taking an interpreted structure from one dimension and putting it in the context of a structure in the other dimension, where it can subsequently be interpreted *in terms of* the dimension traveled to. Most clearly we see this in the case of functional interpretation, where a string interpreted in the surface dimension travels to the deep dimension to be interpreted there as performing a specific function.

Where the compositional feature of F *is* reflected is in composition in the deep dimension. There we have structures like "$(\Delta : w)$" - a valency slot Δ filled with a string of the required wordclass. We take the following equations as defining the basic interactions: (1) $\Delta/_F w \bullet_F w \rightarrow \Delta : w$ and (2) $\Delta/_F w \bullet_F w \backslash_F \Delta \rightarrow \Delta : w$. Both times, the product $\bullet_F$ combines $\mathcal{W}_s \times \mathcal{W}_d$ to a formula interpreted on $\mathcal{W}_d$.

Subsequently, we can formulate the proof theoretical part of our logical grammar. Again, what we want to formalize is the construction of a sentence's deep structure or *tectogrammatical representation* (TR), given that sentence's surface form, whereby the TR is a dependency structure, as detailed out section 2.

The formulation we employ here is that of Hepple's approach to MMLG, e.g. [1]. First, we define the mode-internal axioms. These axioms specify the principal logical behavior of each of the modes, i.e. what is common to all. We represent the axioms as a *natural deduction system*, in the sense that we use formulas of the form $m \vdash C : s$, m being the composition built up (*marker term*), C the type, and s the proof term. The marker term m provides the structure according to which proper control over the deductive inference is excercised, whereas the proof term s is a lambda term building up the *meaning* of the term. s will provide us with the TR of the sentence in case the proof can be concluded (i.e. category s in C). We omit the rules here for space reasons - they are the standard elimination and introduction rules for $\{\backslash_*, /_*, \bullet_*\}$.

In addition, we specify the axiom schemata for modes, being associativity, linkage, and permutation. These axioms are axiom-*schemata* in the sense that we have to specify further for which modes the schemata can be instantiated. Once instantiated, they provide the *structural rules*, and it is these rules that can make available a complete range logics within our system.

For instance, let us consider s (surface) and τ (deep) as non-associative and non-permutative modes. Then an analysis of "Joop bought a ticket" is as follows:

$$\dfrac{\dfrac{Joop \vdash n \quad bought \vdash \{(Actor/_F n)\} \backslash_\tau s/_\tau \{(Patient/_F n)\}}{(Joop \circ_\tau bought) \vdash s/_\tau \{(Patient/_F n)\}} \qquad \dfrac{a \vdash n/_s n \quad ticket \vdash n}{a \circ_s ticket \vdash n}}{Joop \circ_\tau bought \circ_\tau (a \circ_s ticket) \vdash s}$$

with the label s simultaneously building up as follows (β-reduction directly applied):

$$\dfrac{\dfrac{Joop : \mathbf{Joop} \quad bought : \lambda l_1, r_1.\{(l_1 : ACT)\}\mathbf{buy}\{(r_1 : PAT)\}}{(Joop \circ_\tau bought) : \lambda r_1.\{(I : ACT)\}buy\{(r_1 : PAT)\}} \qquad \dfrac{a \vdash : \emptyset \quad ticket : \mathbf{ticket}}{a \circ_s ticket : \mathbf{ticket}}}{Joop \circ_\tau bought \circ_\tau (a \circ_s ticket) : \{(\mathbf{Joop} : Actor)\}\mathbf{buy}\{(\mathbf{ticket} : Patient)\}}$$

Finally, concerning the distinctions IP/FM and OBL/OPT, the logic (by default) models IP/OBL. For FM, we introduce a structural rule that allows one to expand a head by a dependency Δ if the head *was* already expanded once by that dependency relation, and Δ is marked as ϕ or ψ. Optionality is modeled by a structural rule enabling one to drop a dependency relation if it is decorated by ψ, ω. [3].

---

[3] Note that our mode τ is quite restrictive, and does not enable us to do extraction. For that, we could define an associative, permutative mode ϵ to capture extraction from any position, and instantiate the linkage axiom of definition 2 as $[\tau/\epsilon]$, [2].

3.3. **Linguistic Structures & Linguistic Signs.** Some interesting observations can be made concerning the notion of *linguistic sign* underlying our linguistic structures. Essentially, what a linguistic sign is purported to express is the relation between a linguistic *form*, like a sound, word, etc, and its *meaning*. The most prevalent, contemporary notion of linguistic sign was introduced by the Swiss linguist Ferdinand de Saussure. In his opinion, a linguistic sign was a binary opposition between "signifiant" and "signifié". The signifier, the *form*, has a direct reference to the signified, its *meaning*. It is this 'direct'-ness, or 'unmediated'-ness, that has proved to be advantageous in mathematical descriptions of natural language in the form of the relation between (syntactic) formulas and (semantic) types, but it is also an aspect which has been criticized, notably by Roman Jakobson. Jakobson discusses Saussure's views in various papers, and adopts a notion of linguistic sign that is explicitly modeled after Charles Peirce's notion of *triadic* sign. Specifically, Jakobson argues that the signifier/signified-opposition as such is artificial in the sense that the *whole* should be taken into account as well, not just its parts.

Applied to our dependency-based view on grammar, we can see that it is this notion of linguistic sign that is embodied in our logic, and not the Saussurian sign. Because, a string at surface is interpreted as fulfulling a particular function at the deep level by virtue of the larger context - the best example of such a context being a valency frame. It is dependent on the present valency frames how particular strings will get interpreted as playing specific roles. Moreover, the separation into surface and deep dimension, related via a functional mode $\mathcal{F}$, loosens (*relativates*) the strict relation between categorial assignment and interpreted type.

4. Word Order & Structural Indications of Informativity

The basic idea about word order in DBLG is that a valency frame specifies the order in which modifiers are to occur (according to their respective dependency relations, that is - which are ordered according the language's systemic ordering (section 2))[4]. From such a valency frame we obtain a lexical category by including the head position explicitly - the lexical category specifies the order in which modifications have to occur relatively to the head.

Given the nature of our notions of functional interpretation and realization ($\mathcal{F}$) we obtain a rather strict relation between the order specified in the lexical category (related to the deep word order) and the order in which interpretable strings have to appear in the surface form. Any deviation from the systemic ordering can, therefore, not be accounted for, since such flexibility is not available in the system we defined above.To accommodate structurally for the possibility of (modifier) movement, we introduce a mode $\pi^{\leftrightarrow}$ that makes permutation available. However, in regard to the issue of *what* should be able to move, we don't want to make $\pi^{\leftrightarrow}$ available to every element. We propose to mark moveable elements with a Δ in the lexical categories. If we define $\pi^{\leftrightarrow}$ as a rule making full permutation available, then elements will be able to travel to a more leftwards position as well as to a more rightwards position. In some languages, this is undesirable (e.g, rigid head-finality). We can overcome this problem by introducing a further two modes, $\pi^{\leftarrow}$ and $\pi^{\rightarrow}$, that allow for left- respectively right-permutation only. To make these modes accessible, we decorate terms with $\triangleleft$ or $\triangleright$, respectively.

For instance, consider the lexical category $\{(Time-When/_{\mathcal{F}}n)^{\triangleright},(Actor/_{\mathcal{F}})\}\backslash_{\iota} aus/_{\tau}\{(Actor/_{\mathcal{F}})\}$ for "read". Then, "Yesterday I read a book" as well as "I read a book yesterday" will have derivable tectogrammatical representations.

The interesting fact about moved modifiers is that they (structurally) indicate (a change in) informativity of their semantic counterparts. At least for written

[4]Note that we are interested in *deep* word order here

sentences, where intonational cues are not available to us, we can assume a default configuration of indications of informativity, and perceive changes relative to such default configuration. For example, a (written!) sentence like "Yesterday John read a book" would have the CB/NB-boundary after the verb, thus leading to "a book" being interpreted as NB and the rest as CB. However, if we move "Yesterday" to the sentence-final position, then such induces a change in the CB/NB-configuration, with "a book" now being considered CB and "yesterday" NB. In [2] we consider a small set of hypotheses that covers the impact of movement on the CB/NB-ness of the moved modifiers themselves, as well as the impact on the 'remaining' (i.e. unmoved) modifiers/heads.

What is interesting about these hypotheses is that we can formalize these hypotheses relatively straightforward. To start with, according to one hypothesis, we introduce a structural rule that would allow us to infer a default CB/NB-configuration if we have not yet made the move from τ to a movement-mode. Subsequently, the other hypotheses are modeled by rules that enable us to *change* that default markup.One hypothesis applies in case of leftwards movement - thus, whenever the structural rule for $\pi^{\leftarrow}$ is being used, such should result in a change to a classification as contextually bound. Similarly for the use of rightward movement - only then such applies in case of $\pi^{\rightarrow}$, with a change into contextually nonbound.

5. Relations to a Logic of Topic and Focus

Although our hypotheses are still relatively crude with respect to others proposed by for example Hajičová, what we do aim to provide with them is a structural ground for the semantical notions of topic and focus. Characteristic for the Praguian notions is that they are not primary notions, like in other frameworks, but are derived from the notions of contextual boundness and nonboundness. Roughly put, the topic corresponds to the CB modifiers of a verbal head, and the focus corresponds to the NB modifiers. Depending on whether the head itself is CB or NB, it belongs to the topic or the focus, respectively (cf. [6],p.216f). Following Peregrin's proposal for a logic of topic and focus [4], we can thus take the lambda term s constructed in a proof, and transform it into a logical representation which is truth-semantically sensitive to the topic/focus distinction. In [2] we show how not only simple sentences can be dealt with in that manner, but also complex sentences containing subordinate clauses - by reason of founding topic/focus on the *local* structural characteristics, CB/NB.

Ooops, hier komt de bbl file:

References

[1] Mark Hepple. Hybrid categorial logics. *Bulletin of the IGPL*, 3(2,3):343–356, June 1995. Special Issue on Deduction and Language.

[2] Geert-Jan M. Kruijff. A basic, dependency-based logical grammar. Technical Report UFAL TR-1997-5, ÚFAL MFF UK, Prague, Czech Republic, 1997. Available at `http://kwetal.ms.mff.cuni.cz/~gj/dblg.html`. 80 pages.

[3] Michael Moortgat. Categorial type logics. In Johan van Benthem and Alice ter Meulen, editors, *Handbook of Logic and Language*. Elsevier Science B.V., Amsterdam New York etc., 1996.

[4] Jaroslav Peregrin. Topic and focus in a formal framework. In Barbara H. Partee and Petr Sgall, editors, *Discourse and Meaning: Papers in Honor of Eva Hajičová*. John Benjamins, Amsterdam, The Netherlands, 1995.

[5] Vladimír Petkevič. A new formal specification of underlying structures. *Theoretical Linguistics*, 21(1):7–61, 1995.

[6] Petr Sgall, Eva Hajičová, and Jarmila Panevová. *The Meaning of the Sentence in Its Semantic and Pragmatic Aspects*. D. Reidel Publishing Company, Dordrecht, Boston, London, 1986.

Negative Polarity and Free Choice: Where Do They Come From?

Chungmin Lee *clee@plaza.snu.ac.kr*

Dept. of Linguistics, Seoul National University

1. Introduction

This paper argues, in an attempt at a unified account of negative polarity and free choice phenomena, that the notion of arbitrary choice from among the exhaustive alternative members of the restrictor set is crucial. This function of arbitrary choice is ensured by indefiniteness/nonspecificity of the restrictor common noun involved and the concept of concession or betting/challenge. If the exhaustiveness of the set is emphasized in nonveridical/modal contexts, then the item functions as a free choice strong Det(erminer), and if the item appears in negative or implicitly negative (downward-entailing) contexts, then it functions as a negative polarity weak Det.

2. NPIs Based on Quantificational Scale. In all languages witnessed, a minimal element/unit/value on a quantity scale, often expressed by the indefinite and nonspecific numeral 'one,' together with the concession marker 'even,' functions as a quantitity-based NPI. Such concession markers as focus markers are 'to' in Korean, 'mo' in Japanese, 'bhii' in Hindi, 'ye' in Chinese, 'ch' in Mongolian, etc. (Haspelmath 1993 show other such concession markers occurring on NPIs in some 12 languages from among samples from 40 languages). Consider:

(1) a. Not even one (single) friend came./ ?*Even one (single) friend came.

b. neg kun ch ir egui /*sen

one person even come not-Past/*Past

'Not even/*even one person came.' [Mongolian]

Note that the affirmative counterparts both in English and Mongolian are unacceptable or uninformative, and we can view the combination of 'even' and 'one' as an NPI in any language. Here, the minimal natural number 'one' is naturally combined with some countable common noun denoting a whole non-dividable unit individual, along with a classifier in numeral classifier languages, or with some mass noun, along with a measure function unit like 'drop'/*pangwul*. Scientific measure units like *gr, cm, l*, unlike folk taxonomic units usually realized as classifiers, are not so effective, though possible, for negative polarity, because decimals below 1 are possible and the 'minimal/bottom' is not clear. The word *ssal* 'rice' is either a mass or count and NPIs are possible in both ways: *ssal han*[one] *toeppak*[measure=0.444 gallon]-*to*[even] and *ssal han thol*[grain]-*to*. Alternatives on a scale are hierarchically linearly ordered, though 'disjunct' and aided by 'equivalence classes' in mass, as indicated by Krifka (1990). The concessive element 'even' is omissable in rather frozen contexts where the concept of concession is obvious, in some languages.

The numeral 'one' in (1) can be replaced by other alternative numerals like 'three' and then different phenomena occur in different languages. in languages such as English and Japanese, the affirmative counterparts become rather acceptable, though with the changed new meaning of 'as many as' (surprisingly/unexpectedly), as in (2) below, and in languages like French and Korean, they remain unacceptable, as in (3): :

(2) a. (?)Mary solved even three problems.

b. Mary-wa mondai -o mittu -mo toketa

Top problem Acc three even solved

'Mary solved as many as (even) three problems.'

(3) a. Marie a resolu meme pas/*meme trois problemes

'Mary solved fewer than three/*even three problems.'

'Mary didn't solve as many (more than 3) problems as expected (*meme pas*).'

b. Mary -nun se munje -to mos phul-oss-ta/*phul-oss-ta

Top three problem even Neg solved /solved

'Mary solved fewer than three/*even three problems.'

In Korean, the same marker (*-to*) cannot be used for the new implicature 'as many as' but a different marker (*-i-na*) must be attached to the indefinite nonspecific numeral expression (so *se munje-i-na* 'as many as three problems') for the new situation. The concession focus expression 'even' and its equivalents in other languages trigger a relevant implicational quantificational scale (Fauconnier 1975), and, further, as I argue, when combined with 'one' or other indefinite and nonspecific, contextually minimal quantity/degree expression, constitutes a type of NPIs, a strong type at least in Korean, requiring an antimorphic operator, i.e., an overt negation or anti-additive 'before'/'*V-ki con-e*' clauses. In English, '*even one* N' can be licensed by 'before' clauses (e.g., 'Before even one friend came, Mary left.') like in Korean and even by interrogative sentences (e.g., 'Did even one friend come?') unlike in Korean but not by 'after' clauses (e.g., *'After even one friend came, Mary left.') like in Korean, as expected. The NPI *ever/han pon -to* (in Korean) 'even one time' has the concession concept incorporated, meaning 'even once,' going down to the minimal event frequency (making concession).

If a given numeral/minimal expression is indefinite and nonspecific, it is non-referential and thereby a hypothetical quantificational scale is triggered, because of the concession element, to give a universal negation in negative contexts or weaker polarity effects in other licensing contexts. Concession arises by going down the scale to the likeliest bottom element to deny (or suspect) it. If an expression is definite/specific (including definite/specific numerals or minimals), occurring with the same marker *-to* in Korean or *-mo* in Japanese either in monotone increasing or decreasing contexts, then its inclusion ('also') sense gets predominent and does not function as an NPI any longer. A parallel ambiguity (or underspecification) between 'also' and 'even' occur in Hindi (Lahiri 1995) and many other languages. Concession implies admission/inclusion. A specific indefinite numeral NP, however, cannot constitute an NPI. Consider:

(4) nae-ka al -nun kanhowon han myong -to (an) o -ass -ta

I Nom know Rel nurse one Cl also/even not came

'(Even) A nurse I know (also) came/didn't come.'

Nonspecificity as well as indefiniteness is required for negative polarity, as can be noticed above in Korean and in English (as translated). No special stress is needed in this case, even though a strong focus stress is necessarily assigned to the numeral *han* 'one' in a numeral NPI in Korean. A non-numeral definite noun plus *-to* (concessive marker) can also take either an affirmative or negative predicate and in the latter case some NPI effects occur based on a highly contextually determined limited scale.

The sentences of (1) above are said to originally 'assert' something like: $\neg\exists x[\text{ONE}(x) \wedge x \text{ person} \wedge x \text{ came}]$, and implicate (2) below, and (3) can follow:

(2) a. $\neg\exists x[x>\text{ONE} \wedge x \text{ person} \wedge x \text{ came}]$ (x = a natural number)

b. likelihood($^\wedge\neg\exists x[x>1 \wedge x \text{ person} \wedge x \text{ came}]$) > likelihood ($^\wedge\neg\exists x[x=1 \wedge x \text{ person} \wedge x \text{ came}]$)

(3) $\neg\exists x[\text{ONE}(x) \wedge x \text{ person} \wedge x \text{ came}] \rightarrow \neg\exists x[x>\text{ONE} \wedge x \text{ person} \wedge x \text{ came}]$

Here, 'ONE' must be minimal and the minimum is ensured by the CONCESSION operator. Then, the alternatives to 'ONE' are limited to any higher natural numbers than one on the scale. A syntactically definite superlative expression is also semantically nonspecific/ non-referential when used for negative polarity effect.. The triggering of such a quantificational scale is an ample source of idiomatic NPI expressions such as 'lift a finger,' 'a drop,' *nunkkop-mankhum-to* 'even as little as matter in the eye' and 'let alone -'*l-kosahako/khonyong* . However, application of this kind of NPIs is limited to quantity-based situations and Lee and Horn (1994) and Lahiri's (1995) identification of this quantity(/degree)-based negative polarity with 'any' cannot hold; 'any' is a more general type of NPI that involves a quality dimension as well, as shown below.

3. Negative Polarity Based on Quality. 'Any' in English, its equivalent 'amu' in Korean and wh-indefinite NPIs in many languages are based more on arbitrary choice from among the possible alternatives in the restrictor set than on quantity alone. The common noun head can be specified by all sorts of adjectives and 'any' stands for all the possible intersective (not 'fake,' 'alleged,' etc.) adjectives and modifiers, like a big variable. So, the problem to Heim (1984) and Krifka (1990) of 'poisoned fruit' in 'If you eat *any* fruit, you will feel better' is not a problem. It is simply filtered out by nonmonotonic common sense reasoning and the Cooperative Principle. The purpose of '(eating) fruit' must be for nutrition and health (cf. Pustejovsky 1995) and there remains a matter of coherent and relevant relation between the antecedent and the consequent in an act of offer or advice, not a matter of inclusion in the anti-additive or monotone decreasing 'if.' You can get 'If you import *any* poisoned fruit, you will be punished.'

Likewise, 'any answer' in 'I didn't get any answer' could be either negative or positive rather than one or more answers, requiring a quality ('subproperties' a la Krifka 1990) dimension in the alternative set, rather than a quantity dimension on a scale. This is why indefinites from wh-words, with concession, function as NPIs in predominently many languages such as Basque, Japanese, Chinese, Hindi, Mongolian, Greek and Korean. **A wh-question is a set of alternative answers as true propositions (Hamblin 1973) and an indefinite from it can stand for any arbitrary member of the same set.** A wh-word needs a separate information focus on it, whereas an indefinite does not. Arbitrary choice from alternatives is done by concession or betting/challenge (by disjunctive elimination) game-theoretically such as 'You choose whatever, still I win' (strategically from easy ones up to exhaustion — but Kadmon and Landman 's 1993 'widening' is not quite enough). In order to emphasize arbitrariness via concession/challenge, focus is needed for this type of NPIs. This is crucially distinct from quantity-based negative polarity. Korean has a general type of negative polarity determiner *amu* just like *any*, along with a type of NPIs from wh-based indefinites such as *nuku-to* 'anyone,' *otton* 'certain' N-*to*, *musun* 'sm kind of' N-*to*, etc., occurring with -*to* 'even.' Then, consider the following question and answer pair:

(4) nu(ku)-ka o -ass -ni?
who Nom come Past Q
'Who came?'

(5) a. amu -to an o -ass -o
any even not come Past Dec
'Not anyone came.'

b.???han saram -to an o -ass-o [appropriate to 'How many came?']
one person even not come Past Dec
'Not even a (single) person came.'

c. (?)nuku -to an o -ass -o
wh- someone even not come Past Dec
'Not anyone whosoever came.'

d. dare 'wh-sb' -mo 'even' konakatta 'not came' (Japanese)

e. shei 'wh-sb' -ye 'even' mei you lai 'not came' (Chinese)

As an answer, (5a) is all right, with the general type of NPI *amu-* in it. The answer with quantity-based NPI (5b) is not appropriate (*han saram-to* can be replaced by a more emphatic idiomatic *kaemi (saekki) han mari -to* 'even a (baby) ant' and still inappropriate). The one with the NPI based on wh-word (5c) is tolerable and *nuku* 'wh-someone' here can be replaced by *otton saram* 'wh-certain person,' which represents (sub)properties and (sub)kinds, and the wh-based indefinite NPIs in other languages (5d,e) are all right in the same situation. Hindi also has the quantity-based *ek bhii* 'even one' besides *koii bhii* 'any(one)' from *koii* 'someone' as NPIs, just as all other languages. In Basque, all the series of indefinites commonly have wh-forms:

(6) a. ***nor*** 'who' *nor-bait* 'someone' *i-nor* 'anyone' NPI *edo-nor* FC
    f. ***zer*** 'what' *zer-bait* 'something' *e-zer* 'anything' NPI *edo-zer* FC

The majority 57 out of 100 languages investigated by Haspelmath (1993) base their NPIs on indefinites from wh-words. 'Any'/'amu' as well as wh-indefinite-based NPIs has the sense of concession: 'even if you choose whatever---,' 'wh- ever --- may,' etc. When arbitrariness is extreme via concession and conventionalized, negative polarity arises. The French concessive construction *qui que ce coit* is now an NPI/FC (Larrivee and Lee 1997).

4. Free Choice. If arbitrariness is so emphasized as to exhaust the whole set in choice, then free choice as a strong Det arises, requiring uncertainty modal contexts, and it cannot occur in existential constructions. It gets a universal reading in the proper contexts. Otherwise, negation is so strong that the same or similar item becomes weak/existential, functioning as an 'NPI.' Examples of wh-indefinite FCs:

(7) a. dare-de-mo iidesu (Jp) b. 'shei -ye'(rise-tone on 'ye') hao (Ch)
    b. nuku -i-ra -to coh-ta (Kor)
    (a, b. c) 'Anyone will do (be good, OK, fine).'

The Korean and Japanese free choice items are from concessive clauses (*nuku-i-ra-to*[any-be-Dec-even] 'whoever it may be'). The predicates are all (deontic-permission) modal predicates, which are monotone decreasing or even anti-additive ('You may dance or sing' ↔ . 'You may dance and you may sing' or the subject can be disjunctive: 'You or she may dance'↔ 'You may dance and she may dance.' Similarly, 'Anyone is OK' is subject to the same anti-additive function. Consider:

(8) a. $OK(a \vee b \vee c \vee d \vee e, ---) \leftrightarrow OK(a) \wedge OK(b) \wedge OK(c) \wedge OK(d) \wedge OK(e),---$
    h. $f(X \vee Y) \leftrightarrow f(X) \wedge f(Y)$ [anti-additive]

By disjunctive elimination of all the possible members in the restrictor set, you can reach the universal reading status. In an affirmative universal statement, you cannot have this process and this is the difference between FC and universal quantification. Therefore, many languages show a disjunction marker attached to a FC item, e.g., *edo* 'or' in Basque above and *–i-tunci* 'whether or'/-i-*na* 'or'/*-i-kon* 'or,' variant FCs in Korean. Even in case where such an NPI/FC-derived form such as 'dare-mo' is used as a universal quantifier as in Japanese, it still prefers modal contexts and needs an additional universal quantifying adverb (*minna*) for full acceptability in non-modal contexts. Other modals including a generic, which I view as a necessity/conditional modal, license FC. Therefore, the Topic position of a generic statement can have a disjunction to get the monotone decreasing or anti-additive effect (e.g., *ilponin-i-na hankukin-un pap-ul mok-ko san-ta* 'Japanese or Koreans live on rice').

In Korean, weak NPIs have the same concessive clausal form as FC: *amu/wh-indefinitDet N-i-ra-to,* occurring in *kikkothaeya/kocak* 'at most,' *-myon* 'if,' generic-modifying clauses, questions asking about volition/experience and the 'too to' construction. However, unlike FC, they are not stressed. The strong type of NPIs in Korean, *amu N-to* and some *wh-indef N-to* are licensed by overt negation, the 'before' clause, and the comparative construction, and another strong NPI *pakke* 'beside, except' can occur in a rhetorical question. So, there does not seem to exist any NPI that occurs only with the anti-morphic functor, negation, differently from Nam (1993)..

5. Concluding Remarks

There is a vast spectrum of indefiniteness: wh-words, indefinite Dets/pronouns, NPIs--weak and strong, and FC. They are all significantly interwoven with each other and their functions are differentiated by means of focus and relevant prosodic features as well as morphosyntactic features. In particular, negative polarity and free choice are based on the same principles from (decreasing) monotonicity to anti-morphic function on the basis of quantity and quality. Some idiomaticity and cross-linguistic variation call for a 'lexical' way of viewing the matter but we must try to further our understanding of fundamental universal principles. .

Children acquire negative polarity a few months before age two, earlier than free choice. The generic nature of FC must be tougher to children than the emphatic universal negation - strong negative polarity. We need more investigations into the interaction between diverse speech acts (question and command) /'rhetorical' /sophisticated/emotive aspects of language use and explicit logical relations.

References

Fauconnier, G. (1975) Lee, Y. and L. Horn (199) Kadmon, N. and F. Landman (1993)

Larrivee, P. and C. Lee (1997) Krifka, M. (1990) Lee, C. (1996)

Haspelmath, M. (1993) Pustejovsky, J. (1995) Heim, I. (1984)

Lahiri, Utpal (1995) 'Negative Polarity Items in English and Korean,' *Lg Sciences* 18: 503-23.

Nam, S. (1993)

Two dynamic strategies

Alice ter Meulen*
Philosophy, Indiana University (Bloomington)

Abstract

The dynamics of semantic interpretation may be located in two natural components of an interpretive system: either in the processes that construct the syntactic representation, or in those that perform the evaluation in the models. Both strategies have been implemented in current dynamic systems of interpretation; the first for instance in DRT, the second in DPL. This paper compares the two strategies, using the real life example of temporal reasoning in natural language. The focus is on the logical issues, in particular the compatibility of the two forms of dynamics, the structure of their action repertoires, and the interaction of interpretation and inference.

1. Introduction

The Dynamic Turn in the semantic theory of both formal and natural languages has created a proper perspective for explicit logical theorizing about the dynamics of information flow and its associated cognitive processes. In this research program a new key issue emerges which dynamic processes are relevant to specific cognitive tasks, e.g. to natural language understanding - the concern of this paper. A dynamic theory of information flow in natural language should ideally provide models of our human cognitive capacities of information processing.

In a classical Tarski-style truth-conditional logic three components are customarily specified in recursive definitions:

(1) the syntactic objects (representation)
(2) the truth-conditions (evaluation)
(3) the intended models (ontology)

Two major dynamic approaches are presented in the current literature that provide different toolkits, disregarding momentarily for simplicity procedural alternatives such as gametheory. One is the representational tradition of Discourse Representation Theory (DRT, Kamp 1981, Kamp & Reyle 1993), fed by computational linguistics, which locates the dynamics in the construction of the representation. The other is the translational tradition of Dynamic Logic and Dynamic Montague Grammar (DPL, van Benthem 1996, Groenendijk & Stokhof 1991), fed by modeltheory, which locates the dynamics in the semantic evaluation in its models. Abstracting away from the details of these systems, the two paradigms are here called:

(1) Dynamics of Representation (DoR)
(2) Dynamics of Evaluation (DoE)

The logical system of belief revision developed by Gardenfors and others is another example of the DoE school, whereas the Dynamic Aspect Trees of ter Meulen (1995) clearly belong to the DoR school.

It is certainly possible to design dynamic systems that mix these two strategies, for instance, by structuring the states of DoE systems as trees,

making variable-assignments relate trees. Systems that locate the dynamics in the representation may induce at least some tinkering with classical truth conditions. Systems that locate the dynamics in the evaluation may require enriched syntactic objects, adding special variables or connectives. By adding transitions or processes as first-class citizens, as in Arrow Logic (cf. van Benthem 1994), even the third Tarskian component of the ontology could also be a domain of dynamics. In fact, there may well be a continuum of DoR/DoE pairs daisy-chaining the syntax of natural language eventually to its intended models. But drawing this conceptual distinction between the two approaches sharpens their methodological differences and may clarify the abstract options that are available in designing dynamic systems. The common term 'interpretation' is ambiguous between these two dynamic conceptions, as well as its classical static Tarskian definition. The present paper focuses only on the dynamics of representation and the dynamics of interpretation, to compare their methods, raise some issues about their connections, and properties as systems of interpretation and inference.
Given our belief that, with enough remodeling tricks, Fregean/Montagovian compositionality can always be achieved one way or another, the debate between representationalism and non-representationalism, conducted under the heading of 'compositionality', demonstrates the formal 'extensional' equivalences between the two approaches, leaving the essential 'intensional' differences in operating styles and logical insights still to be analyzed.

2. Temporal reasoning

Temporal reasoning, the early source of linguistic inspiration for natural language semantics, also for DRT, is a domain with a strong visual flavour, responsible for the many pictorial representations of temporal objects and relations that abound in the literature. People have vivid intuitions about the flow of time, and provide strong judgements on the acceptability of inferences about temporal relations. In Montague Grammar Priorian tense logics are interpreted in either pure point structures or in richer intervals (Dowty 1979), where unary operators and more complex ones (e.g. interval conjunction) are definable. In the logical syntax, the full language admits arbitrary nestings of tense operators and arbitrary negations. Fragments of natural language are, however, limited to atomic negations (via polarity), restricted disjunction and operator nesting. Kamp first demonstrated the limitations of static Priorian systems, as Kamp & Rohrer (1983), Partee (1984), Kamp & Reyle (1993) and van Eijck and Kamp (1997) presented representational accounts of temporal reasoning, motivated by linguistic considerations. The corresponding DoE treatment was first presented in Dekker (1993) with update conditions, dynamic inference, and some deviant structural rules.The DoE strategy in Dekker (1993) is to capture explicitly the nuts and bolts of the DRT processes of context change for temporal anaphora from Partee (1984). His approach requires (i) a very rich logical language with an equally rich ontology in the models, (ii) encoding the context change potential of aspectual properties at the lexical level in the translation and (iii) introducing invisible sentential connectors to formalize the shifting of reference times in discourse, and (iv) a syntactic indexing mechanism for verbs and prepositions to ensure they are interpreted as properties of the same event.

First, an equivalent Tree Calculus (TC) is presented here with open and closed nodes, attachment and annotation actions, embedding of trees in models (cf. van Benthem (1997)), where the version for intervals is just a poly-modal version of the point system and binary temporal operators may be added. TC consists of the following components:

(1) a unique designated active or current node
(2) a number of additional nodes
(3) three kinds of constructive actions
  (i) add a node
  (ii) change the active node
  (iii) add a label

In TC the states related by actions are trees, not merely flat assignment functions as in DPL. Actions are used to construct trees, and modal operators may label the nodes in the trees to describe the local tree structure. In DRT the adding of event-reference markers corresponds to the adding of nodes in TC, but DRT requires their introduction to be accompanied with descriptive conditions in which they occur. In TC the action of adding a label (content) is independent of the addition of nodes. The way in which the current reference time is shifted in DRT is by adding conditions stating the temporal relations. In DATs the three kinds of constructive actions are merged into the rules to construct trees with two sorted nodes, coding where new nodes are to be appended. Holes, or open nodes, allow for dependent nodes to be introduced; plugs, or closed nodes, do not and force the new node to be introduced as right-sister. But the DAT system admits adding labels without adding new nodes, for stative information is treated as stickers which add labels to existing nodes. Where TC tests a proposition *p* in a model,

$$M, t_1, t_2 \models p,$$

Dynamic Tense Logic expresses the corresponding test as

$$t_1 = t_2 \ \& \ t_1 \in V(p)$$

in the model. Update rules may be formulated on trees, for instance, adding F(p) on the current active node may construct a later node at which p is true, but preserving the currently active node. Dynamic evaluation can also be conceived as a real time transition between a beginning time of evaluation and its ending time:

$$(S_{begin}\ t_1)(S_{end}\ t_2) \text{ is a verifying embedding of } p.$$

A theorem is stated that the DTL-style transitions are precisely the <beginning, end> pairs of the succesful embeddings for the representation trees in TC.

Further differences between these DoR and DoE systems resides in the dynamic relations between the speech time, the narrative reference time, and the construction time. Logical differences are also observed between the two approaches: TC need not induce any new notion of consequence, and is compatible with a classical static temporal logic superstructure. It readily suggests variations on the relevant operations: e.g. both sequential ; and parallel || conjunction. It is less linear in its actions, as it operates on two-dimensional representations, where actions may take place, even simultaneously, at distributed locations. For instance, Fp & Fq may be used to construct a branching tree where the two nodes labeled with p and with q respectively are temporally parallel. Temporal DPL might in turn boost its expressive power by complicating its notion of state from assignments, mapping variables to real points in time, to maps from more complex syntactic configurations to temporally structured objects.

3. Inferential actions and Static Inference.

TC and DTL systems still follow the Tarskian scheme of classical logic in its division of labour between syntactic construction and semantic evaluation, as preceding any form of inference. But certain forms of temporal reasoning seem to suggest that an intentional blurring of the separation of interpretation and inference may make for a more natural dynamic system for natural language. In the DoR system for temporal reasoning, DAT (ter Meulen 1995), the main new features in its representational architecture are constituted by three kinds of moves:

(1) spreading of static descriptive information (informational update),
(2) the creation of new structure (temporal update), and
(3) the movement of the point of update activity (perspectival update).

For instance, the representation of a past tense clause creates new temporal structure only when it refers to an event, as opposed to a state. For events, i.e. transitions from beginning to end, the construction rule introduces a new node by simple dependent attachment, when the new information is consistent with the information in the current open node. When the current node is closed or when a local consistency check rejects the new information, the construction rule searches for the lowest node dominating the current node which contains still compatible information, attaching the new information to a newly introduced right sister node. This notion of inference is deviant in several respects. Inference is now relative to a DAT constructed for the premises in sequence and to its current node, which must support the descriptive information of the conclusion. One and the same text may produce different DATs, admitting for different inferences. The TC system models some major features of DATs, making them poly-modal systems, where correctness is guarded by a richer temporal interval logic in the background, including aspectual distinctions. The dynamic operations in DATs are not triggered just by verbal inflections, but by combinations with the aspectual properties of their arguments. Different possible algorithms for running DATs should spell out how much informational update is computed where and when. This invites a division between low-complexity 'inference' with lower case 'i': local consistency management via the knowledge base with some minimal logic, e.g. Horn-clause rules, and 'Inference' in upper case 'I': ternary structural rules for the above format. The actions of inference are dynamic and hence affect the architecture of the DATs. But the more powerful Inference engine verifies conclusions which have no dynamic effect, as they are supported as stickers on the current node of the DAT constructed for its premises. Dynamic inference may employ information from the external knowledge base as an oracle, or it may adduce lexical semantic relations to drive the inference, where the original static meaning-postulates of Montague Grammar now are seen potentially to have dynamic effects in order to preserve the global consistency in a DAT. A second way in which inferential actions may affect the DAT is in the spreading of static information represented in the stickers. Their 'portability constraints' are strongly reminiscent of structural logical rules, e.g. downwards spreading to all dependent nodes is the DAT analogue of equivocating a state with a set of instants between its onset and termination common in interval semantics. Big Inference is still relative to a particular DAT constructed for the premises, its current node and its source node. Since the sticker logic by itself is static and classical, structural rules like MON and CUT are easily seen to be valid.

$$\text{MON} \quad \frac{X, Y \vdash A}{X, B, Y \vdash A} \qquad \text{only when B is a sticker}$$

$$\text{CUT} \quad \frac{X, A, Y \vdash B \qquad Z \vdash A}{X, Z, Y \vdash A} \qquad \text{only when Z is a sticker}$$

In CUT A is already a conclusion, so it is itself a sticker. The new question arises which operations natural languages may have to preserve CUT. It is suggested that expressing information about the past with a present perfect is one such way to cancel whatever dynamic effects the corresponding past tense expression would have had. This is illustrated with examples of natural language reasoning, and compared with their DTL analyses.

Caution should however be taken, for not all common structural rules are valid even in sticker logic. For instance, the order in which stickers are introduced into a DAT is instrumental in some forms of conditional temporal reasoning (see ter Meulen 1995, ch. 5). So stickers are not generally freely permuted as labels of nodes in a DAT. A much more restricted form of Permutation may still apply to allow variation in the order of stickers of the same kind, e.g. two adjacent perfective stickers are permutable as well as two adjacent progressive stickers.

4. Conclusion

In conclusion we discuss what this study teaches us about the use of logic in natural language reasoning, and its consequences for a general theory of cognitive dynamics. The display of information facilitated in the representational strategy provides a natural link to visualizing temporal reasoning, whereas the symbolic encoding of the update processes in DPL produces a compositional translation to an enriched formal language.

5. References

Dekker, P., 1993, *Existential disclosure*. Linguistics and Philosophy 16.6, 561-588.

Dowty, D., 1979, *Word meaning in Montague Grammar*. Dordrecht, Reidel.

Gardenfors, P., 1988. *Knowledge in Flux*. Cambridge (Mass.), MIT Press.

Groenendijk, J. & Stokhof, M., 1991, *Dynamic predicate logic*. Linguistics and Philosophy 14, 39-100.

Kamp, H., 1981, *A theory of truth and semantic representation*. in J. Groenendijk et al. (eds.), Truth, interpretation and information. 1-41. Dodrecht, Foris Publ.

Kamp, H. & Reyle, U., 1993, *From Discourse to Logic*. Dordrecht, Kluwer Academic Publishers.

Kamp, H. and U. Reyle. 1996. A calculus for first-order discourse representation structures. *Journal of Logic, Language and Information* 5, 297-348.

Kamp, H. & Rohrer, Chr. , 1983, *Tense in texts*. in R. Bauerle et al. (eds.), Meaning, use and interpretation of language. Berlin, de Gruyter.

Kamp, H. and A. Rossdeutscher. 1994. DRS-construction and lexically driven inference. *Theoretical Linguistics* 20.2/3. 165-235.

Partee, B. , 1984, *Nominal and temporal anaphora*. Linguistics and Philosophy 7, 243-286.

Seligman, J. and A. ter Meulen. 1995. Dynamic aspect trees. In L. Pólos and M. Masuch (eds.), *Applied Logic: How, What and Why*, 287-320. Dordrecht: Kluwer Academic Publishers.

ter Meulen, A. 1995, *Representing Time in Natural Language. The dynamic interpretation of tense and aspect.* Bradford Books, MIT Press. (Paperback edition with new appendix published in 1997.)

ter Meulen, A., 1997, *Chronoscopes: dynamic tools for temporal reasoning*. Ms. Indiana University.

van Benthem 1994, *Dynamic arrow logic*. in J. van Eijck and A. Visser (eds.), Logic and Information Flow. p. 15-29. Cambridge (Mass.): MIT Press.

van Benthem, J. 1996, *Exploring logical dynamics*. CSLI Publications. Stanford U.

van Benthem, J. 1997, *Dynamic bits and pieces*, ms. UvA/Stanford.

van Eijck, J. and H. Kamp. 1997. Representing discourse in context. in van Benthem and ter Meulen (eds.), *Handbook of Logic and Language*. MIT Press & Elsevier Science Publishers. 179-237.

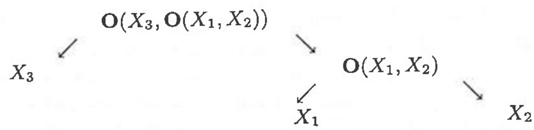
---

* This paper owes its very existence and much of its content to a number of discussions between Johan van Benthem and its actual author. The sole reason for not co-authoring the paper were the programming constraints of the colloquium at which it is presented. The author remains responsible for its content and any errors it may contain.

Parsing as Tree Construction[1]

Wilfried Meyer Viol, Imperial College, London.

Abstractly, the parsing process of an NL string can be viewed as establishing an association between a natural language string a and a set S of terms (formulas) in some logical language, the possible interpretations of a. In your favorite parsing framework, this interpretation is likely to be the result of applying some (set of) basic operation(s) **O** to the representations contributed by the *words* of string a. In fact, the representation is generally a *normal form* under these operations. This means that the association between string a and set of formulas S can be broken down to associations between the individual words of a and sets of representations labelling the *frontier* of a *binary tree* the top node of which is labelled by S:



For instance, we may take X_1, X_2, X_3 to be feature structures and the operation **O** to be unification, or X_1, X_2, X_3 to be lambda terms and **O** Application, or X_1, X_2, X_3 to be labelled categorial expressions and **O** Application:Modus Ponens, or X_1, X_2, X_3 to be DRS's and **O** Merging. In all these grammatical frameworks the construction of terms in a particular parsing process can thus be represented as the growth of decorated binary trees. In this paper we will take the operation **O** to be *function application* in the lambda calculus and the *objects* of the parsing process will be terms in this calculus. Our claim is that there are linguistic phenomena, like *long distance dependencies* which have their proper explanation in this process of tree construction, i.e., independent of the underlying grammatical framework. This paper will suggest a way to treat long distance dependencies in, for instance, Categorial Grammar *without discharge* or in HPSG *without the slash feature.*

Terms as Decorated Trees

In this paper the representation of the logical form of NL strings will take of *labelled* formulas of the lambda calculus. The labels record, among other things, type information and linguistic features like tense, agreement, &c. A formula of the lambda calculus will be represented by a decorated binary trees as follows. The sentence **John read a book**, represented by the formula $\mathbf{read}(\mathbf{john}, \mathbf{some}x\mathbf{book}(x))$, can be seen as resulting from the term

$$\mathtt{APL}(\mathtt{APL}(\lambda x \lambda y \mathbf{read}(y)(x), \mathtt{APL}(\lambda P(\mathbf{some}xPx), \mathbf{book})), \mathbf{john})$$

by β-reduction. The obvious tree structure of this term we will exhibit in the form of a *bracketed formula*: $[_0[_0\mathbf{John}]\ [_1[_0\lambda x\lambda y\mathbf{read}]\ [_1[_0\lambda P(\mathbf{some}xP)\ [_1\mathbf{book}\ ]]]]]$ where 0 represents the left hand and 1 the right hand daughter. Tree and decorations can be considered independently by pulling them apart:

$$\underbrace{[_0[_{00}\ ]\ [_{01}[_{010}\ ]\ [_{011}\ [_{0110}\ [_{0111}\ ]]]]]}_{Tree}\quad \underbrace{\{00{:}\mathbf{john},\ 010{:}\lambda x\lambda y\mathbf{read},\ 0110{:}\lambda P(\mathbf{some}xPx),\ 0111{:}\mathbf{book}\}}_{Decorations}.$$

[1]This research was supported by the UK Engineering and Physical Sciences Research Council under grant reference GR/K67397,

So in this paper, and in [4],[5], this volume, we will write bracketed formulas either nested, e.g. $[_n \ldots [_0 \ldots]]$, or in a sequence, e.g. $[_n \ldots],[_{n0} \ldots]$ (unfolding the indexing in the process), or we use a mixture of both, e.g. $[_n \ldots [_{n0} \ldots]]$. On such a tree, the *destructor* APL, which *applies* a function to its argument, can be seen as a *modal operator*, where tree node n *verifies* APL(ϕ_1, ϕ_2) if ϕ_2, the function, holds at the first and ϕ_1, the argument, holds at the second daughter of n, Now, β reduction APL(ϕ_1, ϕ_2) $=_\beta \psi$, can be represented by (instances of) the *axiom scheme* APL(ϕ_1, ϕ_2) $\rightarrow \psi$, relating the propositions on first and second daughter of n (function and argument) to propositions at n. (see [1]). We will give a formal definition of our basic data structures and the binary trees they are associated with..

Definition 1 (Bracketed Formulas) Given some base language L, a formula of L is a bracketed L-formula, and if $B_1 \ldots B_n$ are bracketed L-formulas and $i \in \{0, 1\}$, then $[_i B_1 \ldots B_n]$ is a bracketed L-formula. The set of all bracketed L-formulas will be denoted by BR_L. If B, B' are bracketed L-formulas, then B *immediately embeds* B', $B \prec B'$, if there is an i such that $B = [_i \ldots B' \ldots]$ and B' is preceded *within* B (that is, not counting '$[_i$') by a balanced number of left and right brackets.[2] For $i \in \{0, 1\}$ and bracketed L-formulas B, B' we set $B \prec_i B'$ if $B \prec B'$ and $B' = [_i \ldots]$. For a bracketed L-formula B, the *tree determined by* B, $\mathcal{T}(B) = \langle TN(B), \mathrm{TrRel}(B)\rangle$ is a tuple where $TN(B)$ consists of the smallest set containing B and closed under $\prec$, and $\mathrm{TrRel}(B) = \{\prec_i | \ i \in \{0, 1\}\}$ consists of the relations of first and second daughter. The set of *decorations* annotating the node B, *Dec*(B), is given by the unbracketed L-terms in B, i.e., $Dec(B) = \{B_1 \in TN(B) \mid B \prec B_1, \neg\exists B_2 \in TN(B) : B_1 \prec B_2\}$.

Starting from the binary tree $\langle T, \prec_0, \prec_1\rangle$ we define an extended structure $\langle T, \prec_0, \prec_1, \prec_\downarrow, \prec_*\rangle$ where $\prec$ is the *immediate dominance* relation and $\prec_*$ the *dominance* relation[3]. On this structure we can interpret modalities $\langle d_0\rangle\phi$ ("ϕ holds on the first daughter"), $\langle d_1\rangle\phi$ ("ϕ holds on the second daughter"), $\langle d\rangle\phi$ ("ϕ holds on some daughter"), $\langle d\rangle^*\phi$ ("ϕ holds here or somewhere below").[4] Over a language L of lambda terms, and type labels we can formulate principles for applicative term trees. For instance, the principles of binary trees, of lambda application, $((\langle d_0\rangle\lambda x\phi \wedge \langle d_1\rangle\psi) \rightarrow \phi[\psi/x])$, unicity of types (no tree node can be annotated by different types), &c. In ([4], this volume) we also consider other tree relations, in particular, a *link* relation which connects a tree node to the root of a second tree.

Constructing Terms

Now, we will view parsing as the construction of a (set of) logical representation(s) guided by the input of an NL string. This can be modelled as (incremental) growth of a (set of) decorated tree(s). In this paper we will take this construction to take place while traversing the NL string from left to right and in a word by word fashion. Every word maps a partial decorated tree to an extension, a decorated partial tree in which it can be embedded. To model this growth Definition 2 gives a partial order $\leq$ between bracketed formulas representing *partial trees*. The input string licenses the growth of a particular collection of trees in the forest of possible trees. From left to right, every word in the string may specifically *license* an extension of the current (set of) partial tree(s) (sentence initial "**John**", "**The**") or it may more generally *constrain* the possible completions of the current partial tree (" **John**

[2]In our notation, $B = [_i \ldots B' \ldots]$ will always entail that B immediately embeds B'.

[3]so $\prec = \prec_0 \cup \prec_1$ and $\prec_*$ is the reflexive and transitive closure of $\prec$.

[4]The converses of these modalities are also of use. We will only mention $\langle u\rangle$ as the converse of $\langle d\rangle$.

who...", '**John**' is going to be some argument in the tree constructed by the relative clause). There are various components to this growth-relation: the growth of tree *structure*, the growth of tree *decorations* and the disappearance, i.e. fulfillment, of *requirements*.

— Firstly, a tree structure may be extended by growing new branches, extending old ones, &c. But the tree structure may also be *underspecified*; It may be undetermined whether some daughter is a left or right one — this we denote by $[_n \ldots [_\downarrow \ldots] \ldots]$ representing the relation of *immediate dominance*. Also, the tree may be underdetermined in the fact that only knowledge about *dominance* is involved — denoted by $[_n \ldots [_* \ldots] \ldots]$. (That is, we extend the notion of a bracketed L-formula.) Now a *partial tree* involves tree relations $\mathrm{TrRel}(B) = \{\prec_i | \; i \in \{0, 1, \downarrow, *\}\}$. In a partial tree $\mathcal{T}(B)$, the fact that one node *immediately dominates* another one does not (yet) mean that the second one is a left daughter or a right daughter of the first one, and that one node *dominates* another one does not mean that these nodes are related by a sequence of immediate dominance steps: this holds only in the (complete) binary trees in which B can be embedded.

— Secondly, in the course of the traversal of the NL string the formulas decorating the nodes of the tree under construction may grow in number but also in information content. That is, as we are in the business of constructing logical formulas we will require placeholders and substitution: at a given point in the parsing process a formula decorating a node of the partial tree may contain a placeholder which later in the process is replaced by a concrete term. No more will be said about this possibility within the confines of the paper.

— Thirdly, the growth of a partial tree is not arbitrary. The string **John read...** leaves us with the structure

$$[_0 \; [_{00} \;], [_{01}[_{010}],[_{011}]]] \quad \{00{:}\mathbf{John},\ 010{:}\lambda x \lambda y \mathbf{read}\}.$$

This structure is a partial decorated tree that cannot be reduced to a λ-free term: at least one argument is still *required* to be able to reduce the tree to a term in the representation language. That is, this partial tree restricts the set of possible completions to the one where an object to **read** is supplied. The growth of partial trees is *directed* towards binary trees, well-formed terms *of type t*. To represent this directedness we divide a bracketed L-formula into a set of *facts* ($DONE$) and a set of *requirements* ($TODO$) (extending the notion of a bracketed L-formula a final time). We will use the notation

$$[_{\text{Tree node}} \; DO \bullet TO].$$

For bracketed L-formula B we set $DO(B) = \{B_1 \in Dec(B) \mid B_1 \text{ left of} \bullet \text{in } B\}$, $TO(B) = \{B_1 \in Dec(B) \mid B_1 \text{ right of} \bullet \text{in } B\}$. Bracketed L-formulas may be nested with the proviso that if B' occurs to the left of $\bullet$ in B, then $TO(B') = \emptyset$: to the left of the bullet we do not find any *unfulfilled* requirements. A tree $\mathcal{T}(B)$ will be called *satisfied* if $TO(B) = \emptyset$[5]. The three components of growth we can distinguish in the following definition.

Definition 2 (The Extension Relation) Given bracketed L-formulas B, B', we say that partial tree $\mathcal{T}(B')$ *extends* partial tree $\mathcal{T}(B)$, notation $\mathcal{T}(B) \leq \mathcal{T}(B')$, if for some $f \in TN(B')^{TN(B)}$ we have $B \leq_f B'$, where

$$\begin{array}{rl} B \leq_f B' \iff & f \text{ a tree homomorphism}, \mathcal{T}(B) \mapsto \mathcal{T}(B'), \\ & \text{such that } f(B) = B' \text{ and } \forall B'' \in TN(B): \\ & -\ DO(B'') \subseteq DO(f(B'')), \\ & -\ TO(f(B'')) \subseteq TO(B'') \cup DO(f(B'')), \\ & -\ TO(B'') \subseteq TO(f(B'')) \cup DO(f(B'')). \end{array}$$

[5]This entails that $TO(B') = \emptyset$ for every $B' \in TN(B)$.

Along the $\leq$ relation, the amount of facts (in DO) may grow, requirements (in TO) may disappear (by becoming facts): the typical case, $[_n ..\phi.. \bullet ..\phi..] \leq [_n ..\phi.. \bullet ..]$. Finally, no new requirements (that are not also facts) may be added.
Given the relation of extension we can fix the notion of a partial tree.

Definition 3 (Decorated Partial Trees) The set BT_L of *satisfied binary L-trees* is given by $BT_L = \{B \in BR_L \mid TO(B) = \emptyset,\ \mathcal{T}(B) \text{ is a binary tree}\}$. The set PT of *partial decorated L-trees* is given by $PT_L = \{B \in BR_L \mid \exists B' \in BT_L, \exists f : B \leq_f B'\}$.

Consequently, a partial decorated L-tree B satisfies two criteria: it can be homomorphically embedded into a binary tree (this excludes for instance circular pathways) and the requirements of B are not principally unfulfillable.

Denotational Semantics

The combination of the extension-relation *between* partial trees, and the modal relations *within* one partial tree supplies the framework for a denotational description of the parsing process. The relevant units are pairs $\langle \mathcal{T}(B), B' \rangle$ consisting of a tree $\mathcal{T}(B)$ and a bracketed L-formula $B' \in TN(B)$. On these pairs we can evaluate L-formulas, that is formulas of the base language, enriched with modalities and logical connectives.

Definition 4 (Denotational L-models) Given a bracketed L-formula $B \in PT_L$, and B' such that $B' \in TN(B)$ then the relation '$\models$' between the pair $\langle \mathcal{T}(B), B' \rangle$ and a formula ϕ is given by

- $\langle \mathcal{T}(B), B' \rangle \not\models \bot$,
- $\langle \mathcal{T}(B), B' \rangle \models \phi$ iff ϕ is an (unbracketed) L-formula and $\phi \in DO(B')$,
- $\langle \mathcal{T}(B), B' \rangle \models \phi \wedge \psi$ iff $\langle \mathcal{T}(B), B' \rangle \models \phi$ and $\langle \mathcal{T}(B), B' \rangle \models \psi$,
- $\langle \mathcal{T}(B), B' \rangle \models \phi \vee \psi$ iff $\langle \mathcal{T}(B), B' \rangle \models \phi$ or $\langle \mathcal{T}(B), B' \rangle \models \psi$,
- $\langle \mathcal{T}(B), B' \rangle \models \langle \# \rangle \phi$ iff there is a $B'' \in TN(B), B' \prec_{\#} B'' : \langle \mathcal{T}(B), B'' \rangle \models \phi$ for some modality $\#$ and its corresponding relation $\prec_{\#}$.
- $\langle \mathcal{T}(B), B' \rangle \models \phi \rightarrow \psi$ if for all $B'' \in PT_L$, and all f such that $B \leq_f B''$, if $\langle \mathcal{T}(B''), f(B') \rangle \models \phi$ then $\langle \mathcal{T}(B''), f(B') \rangle \models \psi$.

Operational Semantics

Spelling out the actual process of construction of the logical representation guided by information culled from the NL string is a task for which an operational semantics describing the actual transitions is best suited.
The initial requirement, the overal goal of the parsing process is the creation of a term of *type* t, the truth value type. The goal of the process is achieved of the root node is labelled with type t and all requirements at the nodes are fulfilled.

$$\text{Axiom: } [_0\ \emptyset \bullet Ty(t)] \qquad \text{Goal: } [_0\ Ty(t), \ldots \bullet \emptyset]$$

Now we have rules developing the initial bracketed formula, the top node of a tree annotated by a requirement to construct a type t term to a full blown binary tree guided by the words of an NL string. Here is a sample,[6]

$$\text{Elimination: } \frac{[_n\ \mathtt{APL}(\psi,\phi) \bullet \ldots]}{[_n\ \mathtt{APL}(\psi,\phi), \chi \bullet \ldots]} \quad \text{Introduction: } \frac{[_n \ldots \bullet \chi]}{[_n \ldots \bullet \chi, \mathtt{APL}(\psi,\phi)]}$$

given $\mathtt{APL}(\psi,\phi) =_\beta \chi$. For instance, $[_0\ \emptyset \bullet Ty(t)]$ may be developed into $[_0\ \emptyset \bullet Ty(t), \mathtt{APL}(Ty(e \rightarrow t), Ty(e))]$, a requirement for a type $e \rightarrow t$ and type e. [7]

[6] We let $\mathtt{APL}(\phi,\psi)$ abbreviate $\langle d_0 \rangle \psi \wedge \langle d_1 \rangle \phi$.
[7] If all requirements are fulfilled, i.e. $[_n\ \phi \bullet \emptyset]$, we will write $[_n \phi]$.

Completion: $\dfrac{[_n \ldots [_0\phi],[_1\psi]]}{[_n \ldots \mathtt{APL}(\psi,\phi),[_0\phi],[_1\psi]]}$ Prediction: $\dfrac{[_n \ldots \bullet\ \mathtt{APL}(\psi,\phi)]}{[_n \ldots \bullet\ \mathtt{APL}(\psi,\phi),[_0\ \bullet\ \phi],[_1\ \bullet\ \psi]]}$

Now, $[_0\ \emptyset \bullet Ty(t), \mathtt{APL}(Ty(e \rightarrow t), Ty(e))]$ may spawn $[_0\ \emptyset \bullet Ty(t), \mathtt{APL}(Ty(e \rightarrow t), Ty(e)), [_0\ \bullet Ty(e)], [_1\ \bullet Ty(e \rightarrow t)]]$; the root node grows into a tree with root, left daughter and right daughter. In this way the requirements generate a forest of admissible trees. By a *Scanning* rule the input words allow the addition of material to the *DO* part, left of the bullet, of nodes in the bracketed formula. This process may depend on the presence of *triggers* in the *TO* part, right of the bullet, of the node currently under consideration.[8] For instance, the lexical entry for **John** requires $TO(Ty(e))$ at the node under the pointer in order to contribute among other things $\{Fo(\textbf{John}), Ty(e)\}$.

$$\text{Scanning: } \frac{[_0 \ldots [\ldots [_k\ \bullet Ty(e)] \ldots] \ldots]}{[_0 \ldots [\ldots [_k\ Fo(\textbf{John}), Ty(e) \bullet Ty(e)] \ldots] \ldots]}$$

Requirements are fulfilled when they occur as facts (as $Ty(e)$ above).

$$\text{Thinning: } \frac{[_n \ldots \phi \ldots \bullet \ldots \phi \ldots]}{[_n \ldots \phi \ldots \bullet \ldots].}$$

And daughters with their requirements fulfilled may be considered facts: $[_n \ldots \bullet [_i\phi] \ldots] /\ [_n \ldots [_i\phi] \bullet \ldots]$.

Long Distance Dependencies

Now, recall that the underlying language L need not be that of the lambda calculus, but may also consist of, for instance, some feature logical one. With this in mind consider now the treatment of long distance dependencies. We deal with these dependencies purely in terms of the tree construction process. Long distance dependencies are initiated by the following rule

$$\frac{[_n\ \emptyset \bullet Ty(t)]}{[_0\ \emptyset \bullet Ty(t), [_*\ \emptyset \bullet Ty(e)]].}$$

A *gap* is adjoined to the starting structure, a requirement for a term of type e used somewhere as an argument in the completed structure. This node with underspecified address, $[_{0*}\ \emptyset \bullet Ty(e)]$, can be 'loaded', for instance, by a sentence initial **What** or **A book**. This results in structures

$$[_n\ [_*Fo(\textbf{What}), Ty(e)] \bullet Ty(t)] \quad [_n\ [_*Fo(\textbf{Some}x\textbf{Book}), Ty(e)] \bullet Ty(t)],$$

setting up the situation for **A book John read** or **What did John read** respectively. That is, the adjunction process adds a node annotated with the requirement for a type e to the tree, with only the information that it is dominated by the root. Having fulfilled the requirement of that node, in every binary tree in which this state is embeddable, the **What** or **Some**x**Book** will be an argument, somewhere in the term. The information in the underspecified node is moved downwards in the process of constructing a tree. This is guided by the *propagation rules*

$$\frac{[_\downarrow\ \phi \bullet \ldots]}{[_0\ \phi \bullet \ldots] \bigvee [_1\ \phi \bullet \ldots]} \qquad \frac{[_n \ldots [_*\phi] \bullet [_0 \ldots], [_1 \ldots]]}{\bigvee_{i \in \{0,1\}} ([_n\ \bullet [_i\phi \ldots]] \bigvee [_n\ \bullet [_i[_*\phi] \ldots]])}$$

[8]So the process is relative to a *string pointer* telling which word of the string is under consideration, and a *task pointer* identifying the node under construction.

where the connective '$\bigvee$' joins alternative developments which may or may not grow into binary trees. We recognize here the modal principles $\langle d\rangle\phi \leftrightarrow (\langle d_0\rangle\phi \vee \langle d_1\rangle\phi)$ and $\langle d\rangle^*\phi \leftrightarrow (\phi \vee \langle d\rangle\langle d\rangle^*\phi)$. After the sequence **What did John...** the *Wh* information has been moved down and ends up in the structure

$$[_0\ \mathrm{Tens(past)}, [_0 Fo(\mathbf{John}), Ty(e)] \bullet [_1\ [_* Fo(\mathbf{What}), Ty(e)] \bullet Ty(e \rightarrow t)], Ty(t)].$$

Here, by the propagation rules, the **What** information is also checked against $Fo(\mathbf{John}), Ty(e)$ at the 00 node. From general principles it follows that $Fo(\mathbf{John}) \wedge Fo(\mathbf{What}) \rightarrow \bot$, thus by $\bot \bigvee[\ldots] \rightarrow [\ldots]$ we are left with the above disjunct. It should be noted that the identification of of the '$[_*$' node with the '$[_j$' node is part of the extension-relation as we have defined it. That is,

$$[_n\ [_* Fo(\alpha), Ty(e)] \bullet \ldots [_j\ \bullet Ty(e)]] \leq\ [_n\ [_j Fo(\alpha), Ty(e)] \bullet \ldots [_j\ \bullet Ty(e)]] \leq$$
$$\leq [_n\ [_j\ Fo(\alpha), Ty(e) \bullet Ty(e)] \bullet\ ] \leq [_n\ [_j Fo(\alpha), Ty(e) \bullet\ ]]$$

Here in the bracketed formula $[_n\ [_* Fo(\alpha), Ty(e)] \bullet \ldots [_j\ \bullet Ty(e)]]$ the formula $[_j\ \bullet Ty(e)]$ represents the *Gap*: a need for a formula of type e which is not fulfilled by the input string. In this case the *Gap* and the *Wh* may be unified.[9]

It is noteworthy that we create island sensitivity of fronted constituents and *Wh* 'extraction' by the fact that the 'star' operator in '$[_* \ldots]$' ranges only over the reflexive and transitive closure of the daughter-relation. When we introduce a *link* relation (in $[_n \ldots [_L\ \ldots\ \bullet Ty(t) \ldots] \ldots]$ the nested bracketed formula is *linked* to the embedding one) , to deal with relative clauses, then this can not be crossed by the star operator thus preventing extraction. However if we need to allow an unrestricted sequence of nodes between some unfixed node and its identification site (see [4] this volume) then we can introduce a more liberal star operator '$[_U$' with the rules

$$\frac{[_n \ldots [_U \phi] \bullet \ldots]}{[_n \ldots [_* \phi] \bullet \ldots]} \quad \frac{[_n \ldots [_U \phi] \bullet [_L\ \ldots\ \bullet \ldots]]}{[_n\ \ldots \bullet [_L\ [_U \phi] \ldots\ \bullet \ldots]].}$$

In this vein, the treatment of long distance dependencies in *Tree Description Grammars* ([2]) LDS_{NL} ([3]) and ([5]) can be formalized. These frameworks explicitly refer to a Kleene star operator. But notice that this mechanism is formulated on the level of abstract trees, *independent* of the particular representation language. This suggests that long distance dependencies can be treated in terms of the parsing process, the construction of representations in general, and do not require a treatment within the underlying grammatical framework.

References

(1) Blackburn, P. , Gardent, C., Meyer Viol, W.: Talking about trees. In *Proceedings of the 6th Conference of the European Chapter of the Association for Computational Linguistics*, pages 21-29, Utrecht, The Netherlands, 1993.

(2) Rogers, J., Vijay-Shanker, K.: Reasoning with Descriptions of Trees. In *Proceedings of the 25th Annual Meeting of the Association for Computational Linguistics*, pp. 72-80, 1992.

(3) Kempson, R., Meyer Viol, W. Parsing as tree construction in LDS. In *Proceedings of 3d Formal Grammar Conference*, pages 147-157, Aix en Provence, France, 1997.

(4) Kempson, R., Meyer Viol, W., Gabbay, D., On Representationalism in Semantics: A Dynamic Account of WH, *Proceedings of the Eleventh Amsterdam Colloquium*, 1997.

(5) Kibble, R., Meyer Viol, W., Incremental Interpretation using a Tree Description Language, *Proceedings of the Eleventh Amsterdam Colloquium*, 1997.

[9] Notice that $[[_j\ \phi \bullet \psi] \ldots [_j \phi']] \leq [[_j\ \phi, \phi' \bullet \psi]]$ holds only if $\psi \in \{\phi, \phi'\}$.

Proof syntax of discontinuity

Glyn Morrill
Universitat Politècnica de Catalunya

The syntactic calculus of Lambek (1958) provides a logical model of language which presents formulas-as-categories and proofs-as-derivations. The calculus, now recognizable as essentially the multiplicative fragment of non-commutative intuitionistic linear logic (Girard 1987), has a sequent calculus with no structural rules, and a proof net syntax which is more geometrical than that of linear logic, for the proof nets are *planar* (Roorda 1991).

Computationally, the proof nets provide the essential structure of derivations. They support, for example, parsing to normal form semantic output without on-line β-reduction (Morrill 1997: 25–30), and memoisation (Morrill 1996), something prohibitive under the shifting premises of hypothetical reasoning in other forms of proof syntax. The proof nets are for categorial grammar what parse trees are for CFG (furthermore incorporating semantics), adding to our paradigmatic slogans: proof nets-as-syntactic structures.

Still, from a linguistic point of view the possibilities of the Lambek calculus are extremely limited since it is a logic of only *concatenation*; works that have aimed at formulating corresponding logic of discontinuity include Moortgat (1988 pt. 3.3, 1990, 1991/96, 1996), Solias (1992), Morrill and Solias (1993), Morrill (1994 chs. 4–5, 1995), Moortgat and Oehrle (1994), Calcagno (1995), Hendriks (1995), and Morrill and Merenciano (1996).

Let us recall the (associative) Lambek calculus **L**. The category formulas $\mathcal{F}$ are given in terms of primitive category formulas $\mathcal{A}$ as follows.

(1) $\mathcal{F} ::= \mathcal{A} \mid \mathcal{F}\bullet\mathcal{F} \mid \mathcal{F}\backslash\mathcal{F} \mid \mathcal{F}/\mathcal{F}$

We interpret category formulas as subsets of the set L of all strings over some vocabulary V. Given an interpretation $[\![P]\!]$ for each primitive category formula P, each category formula A receives an interpretation $[\![A]\!]$ thus:

(2)
$$\begin{array}{lcl} [\![A\backslash B]\!] & = & \{s \mid \forall s' \in [\![A]\!], s'+s \in [\![B]\!]\} \\ [\![B/A]\!] & = & \{s \mid \forall s' \in [\![A]\!], s+s' \in [\![B]\!]\} \\ [\![A\bullet B]\!] & = & \{s_1+s_2 \mid s_1 \in [\![A]\!]\ \&\ s_2 \in [\![B]\!]\} \end{array}$$

A sequent $\Gamma \Rightarrow A$ comprises a succedent category formula A and an antecedent configuration Γ which is a sequence of category formulas. It asserts that in all interpretations, the ordered concatenation of strings in the antecedent category formulas yields a string in the succedent category formula. The valid sequents are those generated by the following sequent calculus.

(3)

a. $A \Rightarrow A$ id $\qquad \dfrac{\Gamma \Rightarrow A \quad \Delta(A) \Rightarrow B}{\Delta(\Gamma) \Rightarrow B}\text{Cut}$

b. $\dfrac{\Gamma \Rightarrow A \quad \Delta(B) \Rightarrow C}{\Delta(\Gamma, A\backslash B) \Rightarrow C}\backslash\text{L} \qquad \dfrac{A, \Gamma \Rightarrow B}{\Gamma \Rightarrow A\backslash B}\backslash\text{R}$

c. $\dfrac{\Gamma \Rightarrow A \quad \Delta(B) \Rightarrow C}{\Delta(B/A, \Gamma) \Rightarrow C}/\text{L} \qquad \dfrac{\Gamma, A \Rightarrow B}{\Gamma \Rightarrow B/A}/\text{R}$

d. $\dfrac{\Gamma(A, B) \Rightarrow C}{\Gamma(A\bullet B) \Rightarrow C}\bullet L \qquad \dfrac{\Gamma \Rightarrow A \quad \Delta \Rightarrow B}{[\Gamma, \Delta] \Rightarrow A\bullet B}\bullet R$

The calculus of Lambek (1958) excludes the empty string ε, and the empty configuration Λ, but they are included here, and we add the product unit I. The definition (1) of category formulas becomes (4).

(4) $\mathcal{F} ::= \mathcal{A} \mid \mathcal{F}\bullet\mathcal{F} \mid \mathcal{F}\backslash\mathcal{F} \mid \mathcal{F}/\mathcal{F} \mid I$

The product unit is interpreted as the set comprising the empty string:

(5) $[\![I]\!] \;=\; \{\varepsilon\}$

The sequent rules are those of (6).

(6) $\Rightarrow I \quad IR \qquad \dfrac{\Gamma_1, \Gamma_2 \Rightarrow A}{\Gamma_1, I, \Gamma_2 \Rightarrow A}IL$

By way of examples of discontinuity beyond the reach of **L** we consider relativisation and in situ binding. In (7) the relative pronoun binds a position which is medial in the relative clause.

(7) (the man) that probably won

Defining the relative pronoun as R/(N\S) or R/(S/N) (where R is CN\CN) allows it to bind only left or right peripheral positions: (7) is not generated. To deal with such cases, Moortgat (1988: 110) defines as follows a binary operator which we write $\uparrow_e$:

(8) $[\![B{\uparrow_e}A]\!] = \{s_1{+}s_2 | \forall s \in [\![A]\!], s_1{+}s{+}s_2 \in [\![B]\!]\}$

Assigning the relative pronoun to category R/(S$\uparrow_e$N) allows both medial and (assuming the ε) peripheral extraction, via the introduction rule (9).

(9) $\dfrac{\Gamma_1, A, \Gamma_2 \Rightarrow B}{\Gamma_1, \Gamma_2 \Rightarrow B{\uparrow_e}A}{\uparrow_e}R$

A satisfactory elimination rule, on the other hand, cannot be formulated, as observed by Moortgat (121–2). Morrill (1992: 13–14) notes that such a treatment potentially accommodates obligatory extraction valencies:

(10) a. (the man) that John assured Mary to be reliable
b. *John assured Mary Bill to be reliable.

If the extraction valency of "assured" is marked by $\uparrow_e$, a sequent corresponding to (10a) is valid while that for (10b) is invalid. However, as pointed out by I. Sag (p.c.), in the absence of an elimination rule it is impossible to actually derive all cases like (10a).

In (11) the quantifier phrase and reflexive are in situ binders, taking scope respectively at the sentence and verb phrase levels.

(11) a. John bought someone Fido.
b. John bought himself Fido.

Moortgat (1991/96) introduces a ternary operator Q for which Morrill (1992: 15) offers the interpretation:

(12) $[\![Q(B, A, C)]\!] = \{s | \forall s_1, s_3, [\forall s_2 \in [A], s_1{+}s_2{+}s_3 \in [B]] \rightarrow s_1{+}s_2{+}s_3 \in [C]\}$

Moortgat categorises quantifier phrases and reflexives as sentence and verb phrase in situ binders Q(S, N, S) and Q(N\S, N, N\S) respectively. Cases such as (11) are generated by means of the elimination rule (13).

(13) $$\frac{\Gamma(A) \Rightarrow B \quad \Delta(C) \Rightarrow D}{\Delta(\Gamma(Q(B, A, C))) \Rightarrow D}\text{QL}$$

However, this time no satisfactory introduction rule can be given. Therefore, as pointed out by H. Hendriks (p.c.), a valid sequent such as Q(S, N, S) $\Rightarrow$ Q(N\S, N, N\S), showing that a sentence in situ binder is also a verb phrase in situ binder, cannot actually be derived.

Based on considerations in Morrill and Solias (1993), Morrill (1994, chs. 4–5; 1995) presents an (unsorted) discontinuity calculus and Morrill (1995, app.) and Morrill and Merenciano (1996) a sorted discontinuity calculus. The former has a sequent calculus with an extraction elimination inference, but does not solve the problems alluded to above. The latter has a *labelled* sequent calculus, and does solve these problems, treating $\uparrow_e$ and Q as defined operators. In a labelled sequent calculus a wider class of sequents is generated by rules for formulas which is then filtered by conditions on labels. However, it would be even more satisfactory to have a one-stage characterisation in the spirit of pure sequent calculus.

In this article we provide such a pure sequent calculus for sorted discontinuity and show how the issues raised above are resolved. We then show how to give proof nets for the operators $\uparrow_e$ and Q treated as units. We hope to present proof nets for the full sorted discontinuity calculus in a longer version of the paper.

In the sorted discontinuity calculus, category formulas fall into two sorts: those $\mathcal{F}$ of sort string, interpreted as subsets of L, and those $\mathcal{F}^2$ of sort split string, interpreted as subsets of L^2. Our definition (4) of category formulas becomes (14).

(14) $$\begin{array}{lll} \mathcal{F} & ::= & \mathcal{A} \mid \mathcal{F}\bullet\mathcal{F} \mid \mathcal{F}\backslash\mathcal{F} \mid \mathcal{F}/\mathcal{F} \mid I \mid \mathcal{F}^2\odot\mathcal{F} \mid \mathcal{F}^2\downarrow\mathcal{F} \\ \mathcal{F}^2 & ::= & \mathcal{F}\uparrow\mathcal{F} \end{array}$$

The discontinuity operators are interpreted by "residuation" with respect to the interpolation adjunction W of functionality $L^2, L \rightarrow L$, defined by $\langle s_1, s_2\rangle W s = s_1{+}s{+}s_2$, in exactly the same way that the continuity operators are interpreted by residuation with respect to the concatenation adjunction + of functionality $L, L \rightarrow L$:

(15) $$\begin{array}{lll} [A\downarrow B] & = & \{s | \ \forall\langle s_1, s_2\rangle \in [A], s_1{+}s{+}s_2 \in [B]\} \\ [B\uparrow A] & = & \{\langle s_1, s_2\rangle | \ \forall s \in [A], s_1{+}s{+}s_2 \in [B]\} \\ [A\odot B] & = & \{s_1{+}s{+}s_2 | \ \langle s_1, s_2\rangle \in [A] \ \& \ s \in [B]\} \end{array}$$

We have, then, $B\uparrow_e A = (B\uparrow A)\odot I$ and $Q(B, A, C) = (B\uparrow A)\downarrow C$.

We have already noted the problem of giving sequent rules for categories of the variety $B{\uparrow}A$: a category occurrence $B{\uparrow}A$ in an antecedent would fail to indicate where one is meant to interpolate. Our analysis is that in the sequent calculus of **L** a category occurrence signals two things: a resource, and the location of that resource with respect to others. This double service can be maintained in view of the continuity of concatenation, but discontinuity requires a distinction between signaling a resource, and its locations of action, which may be multiple. In particular, $B{\uparrow}A$ has two discontinuous components. Our solution is for a split string category formula to appear *twice* in a sequent, at its two loci of action. To mark that the two components are to be taken together as a resource, the occurrences are punctuated as roots, $\sqrt{\ }$.

Sequents come in two kinds, those Σ with sort string succedents, which have string antecedent configurations $\mathcal{O}$, and those Σ^2 with sort split string succedents, which have split string antecedent configurations $\mathcal{O}^2$:

(16)
$$\begin{array}{lcl}
\Sigma & ::= & \mathcal{O} \Rightarrow \mathcal{F} \\
\Sigma^2 & ::= & \mathcal{O}^2 \Rightarrow \sqrt{\mathcal{F}^2} \\
\mathcal{O} & ::= & \Lambda \mid \mathcal{F}, \mathcal{O} \mid \sqrt[1]{\mathcal{F}^2}, \mathcal{O}, \sqrt[2]{\mathcal{F}^2} \\
\mathcal{O}^2 & ::= & \mathcal{O}, \sqrt{\mathcal{F}^2}, \mathcal{O} \mid \mathcal{O}, \sqrt[1]{\mathcal{F}^2}, \mathcal{O}^2, \sqrt[2]{\mathcal{F}^2}, \mathcal{O}
\end{array}$$

Observe that configurations have balanced occurrences of parenthesising punctuation $\sqrt[1]{\ }$ and $\sqrt[2]{\ }$. These mark the two components of split antecedent categories. In a sequent with a split succedent category there is a $\sqrt{\ }$ in the antecedent marking the split point, and around which the parenthesising is balanced. The sequent rules are thus:

(17) a.
$$\frac{\Gamma(\sqrt{A}) \Rightarrow \sqrt{A} \qquad \Delta(B) \Rightarrow C}{\Delta(\Gamma(A{\downarrow}B)) \Rightarrow C}{\downarrow}L \qquad \frac{\sqrt[1]{A}, \Gamma, \sqrt[2]{A} \Rightarrow B}{\Gamma \Rightarrow A{\downarrow}B}{\downarrow}R$$

b.
$$\frac{\Gamma \Rightarrow A \qquad \Delta(B) \Rightarrow C}{\Delta(\sqrt[1]{B{\uparrow}A}, \Gamma, \sqrt[2]{B{\uparrow}A}) \Rightarrow C}{\uparrow}L \qquad \frac{\Gamma(A) \Rightarrow B}{\Gamma(\sqrt{B{\uparrow}A}) \Rightarrow \sqrt{B{\uparrow}A}}{\uparrow}R$$

c.
$$\frac{\Gamma(\sqrt[1]{A}, B, \sqrt[2]{A}) \Rightarrow C}{\Gamma(A{\odot}B) \Rightarrow C}{\odot}L \qquad \frac{\Gamma(\sqrt{A}) \Rightarrow \sqrt{A} \qquad \Delta \Rightarrow B}{\Gamma(\Delta) \Rightarrow A{\odot}B}{\odot}R$$

By way of example, the medial relativisation (7) is treated as follows.

(18)
$$\cfrac{\cfrac{\cfrac{\cfrac{\mathrm{S/S, N, N\backslash S \Rightarrow S}}{\mathrm{S/S}, \sqrt{\mathrm{S{\uparrow}N}}, \mathrm{N\backslash S} \Rightarrow \sqrt{\mathrm{S{\uparrow}N}}}{\uparrow}R \qquad \Rightarrow I}{\mathrm{S/S, N\backslash S \Rightarrow (S{\uparrow}N)}{\odot}I}{\odot}R \qquad \mathrm{R \Rightarrow R}}{\mathrm{R/((S{\uparrow}N)}{\odot}I\mathrm{), S/S, N\backslash S \Rightarrow R}}/L}{\textbf{that+probably+won}\text{: R}}$$

Turning to proof nets for **L** (Roorda 1991), the proof frame for a sequent $A_1, \ldots, A_n \Rightarrow A$ is obtained by recursively unfolding the cyclically ordered polar formulas $A_1^-, \ldots, A_n^-, A^+$ up to atomic literals as follows.

(19) a.
$$\frac{A^+ \quad \text{ii} \quad B^-}{A\backslash B^-} \qquad \frac{B^+ \quad \text{i} \quad A^-}{A\backslash B^+}$$

b.
$$\frac{B^- \quad \text{ii} \quad A^+}{B/A^-} \qquad \frac{A^- \quad \text{i} \quad B^+}{B/A^+}$$

c. $\dfrac{A^- \quad \text{i} \quad B^-}{A{\bullet}B^-} \qquad \dfrac{B^+ \quad \text{ii} \quad A^-}{A{\bullet}B^+}$

The unfolding defines a cyclic total order (chain) $>$ on the literals. A proof structure is a graph of polar formulas that is the result of connecting with an axiom link each literal to exactly one other with the same atom and opposite polarity. A proof structure is a proof net iff it satisfies planarity (Roorda) and the long trip condition (Girard).[1]

Morrill (1996) offers a correctness criterion in terms of unifiability. Here we employ a graph theoretic statement of this criterion. From an axiom linking, construct the graph on i- and ii-vertices (we use numerals and letters respectively below) which has, for each axiom link, an edge between the two vertices immediately inside and between the two vertices immediately outside the link. The correctness criterion is that in the resulting graph no i-vertex be connected to any other i-vertex, or to any ii-vertex from which it is a descendant in the proof frame.

We give the unfolding for $\uparrow_e$ and Q:

(20) a. $\begin{array}{c} \text{i} \quad A^+ \quad \text{i} \\[1ex] \dfrac{B^-}{B{\uparrow_e}A^-} \end{array} \qquad \begin{array}{c} \text{ii} \quad A^- \quad \text{ii} \\[1ex] \dfrac{B^+}{B{\uparrow_e}A^+} \end{array}$

b. $\begin{array}{c} \text{ii} \quad B^+ \quad \text{ii}' \quad C^- \quad \text{ii} \\[1ex] \dfrac{A^-}{Q(B,A,C)^-} \end{array} \qquad \begin{array}{c} \text{i} \quad B^- \quad \text{i}' \quad C^+ \quad \text{i} \\[1ex] \dfrac{A^+}{Q(B,A,C)^+} \end{array}$

Vertically stacked literals are unordered with respect to one another; the upper literals enter into a separate chain which is cyclic: the peripheral vertices are the same. But linking must still be planar in the chains of the partial order.

Consider the proof frame for the medial extraction (7).

(21)

$$\dfrac{0 \quad \dfrac{\mathrm{R}^- \quad j \quad \begin{array}{c} k \quad \mathrm{N}^- \quad k \\[1ex] \dfrac{\mathrm{S}^+}{\mathrm{S}{\uparrow_e}\mathrm{N}^+} \end{array}}{\mathrm{R}/(\mathrm{S}{\uparrow_e}\mathrm{N})^-} \quad 1 \quad \dfrac{\mathrm{S}^- \quad l \quad \mathrm{S}^+}{\mathrm{S}/\mathrm{S}^-} \quad 2 \quad \dfrac{\mathrm{N}^+ \quad m \quad \mathrm{S}^-}{\mathrm{N}\backslash \mathrm{S}^-} \quad 3 \quad \mathrm{R}^+ \quad 0}{\mathrm{R}/(\mathrm{S}{\uparrow_e}\mathrm{N}),\ \mathrm{S}/\mathrm{S},\ \mathrm{N}\backslash\mathrm{S} \Rightarrow \mathrm{R}}$$

The partial order on literals comprises the cyclic chains $0\mathrm{R}^-j\mathrm{S}^+1\mathrm{S}^-l\mathrm{S}^+2\mathrm{N}^+$-$m\mathrm{S}^-3\mathrm{R}^+0$ and $k\mathrm{N}^-k$. We can add the axiom linkings $0\mathrm{R}^-j{=}3\mathrm{R}^+0$, $j\mathrm{S}^+1{=}1\mathrm{S}^-l$, $k\mathrm{N}^-k{=}2\mathrm{N}^+m$, and $l\mathrm{S}^+2{=}m\mathrm{S}^-3$, which are planar in this partial order. The

[1] A crossing is an elementary path in the literal ordering $l_1 > \ldots > l_2 > \ldots > l'_1 > \ldots > l'_2$ where l_1 and l'_1 and l_2 and l'_2 are linked. A proof net satisfies planarity iff there is no crossing. A circularity is a cycle in the proof structure which does not traverse the premisses of any i-node. A proof net satisfies the long trip condition iff there is no circularity.

vertex graph is $0-0, j-3, j-l, 1-1, k-m, k-2, l-3, 2-m$, and satisfies the connectedness constraints.[2]

Bibliography

Calcagno, M.: 1995, 'A Sign-Based Extension to the Lambek Calculus for Discontinuous Constituency', *Bulletin of the Interest Group in Pure and Applied Logics* **3**, 555–578.

Girard, J-Y.: 1987, 'Linear Logic', *Theoretical Computer Science* **50**, 1–102.

Hendriks, P.: 1995, *Comparatives and Categorial Grammar*, Ph.D. dissertation, Rijsuniversiteit Groningen.

Lambek, J.: 1958, 'The mathematics of sentence structure', *American Mathematical Monthly* **65**, 154–170, also in Buszkowski, W., W. Marciszewski, and J. van Benthem (eds.): 1988, *Categorial Grammar*, Linguistic & Literary Studies in Eastern Europe Volume 25, John Benjamins, Amsterdam, 153–172.

Moortgat, M.: 1988, *Categorial Investigations: Logical and Linguistic Aspects of the Lambek Calculus*, Foris, Dordrecht.

Moortgat, M.: 1990, 'The Quantification Calculus: Questions of Axiomatisation', in Deliverable R1.2.A of DYANA Dynamic Interpretation of Natural Language, ESPRIT Basic Research Action BR3175.

Moortgat, M.: 1991/96, 'Generalised Quantification and Discontinuous type constructors', in Bunt and van Horck (eds.) *Discontinuous Constituency*, Mouton de Gruyter, Berlin, 181–208.

Moortgat, M.: 1996, 'In situ binding; a modal analysis', *Proceedings Tenth Amsterdam Colloquium*, Institute for Logic, Language and Computation, Amsterdam.

Moortgat, M. and R.T Oehrle: 1994, 'Adjacency, dependency and order', *Proceedings Ninth Amsterdam Colloquium*, Institute for Logic, Language and Computation, Amsterdam, 447–466.

Morrill, G.: 1992, 'Categorial formalisation of relativisation: pied piping, islands, and extraction sites', Report de Recerca LSI–92–23–R, Departament de Llenguatges i Sistemes Informàtics, Universitat Politècnica de Catalunya.

Morrill, G.: 1994, *Type Logical Grammar: Categorial Logic of Signs*, Kluwer Academic Publishers, Dordrecht.

Morrill, G.: 1995, 'Discontinuity in Categorial Grammar', *Linguistics and Philosophy* **18**, 175–219.

Morrill, G.: 1996, 'Memoisation of Categorial Proof Nets: Parallelism in Categorial Processing', Report de Recerca LSI–96–24–R, Departament de Llenguatges i Sistemes Informàtics, Universitat Politècnica de Catalunya. Also in M. Abrusci and C. Cadasio (eds.) *Proofs and Linguistic Categories*, CLUEB, Bologna, 157–169.

Morrill, G.: 1997, 'Geometry of Language', Report de Recerca LSI–97–45–R, Departament de Llenguatges i Sistemes Informàtics, Universitat Politècnica de Catalunya.

Morrill, G. and Merenciano, J.M.: 1996, 'Generalising Discontinuity', *Traitement Automatique des Langues* **37**, *2*, 119–143.

Morrill, G. and T. Solias: 1993, 'Tuples, Discontinuity and Gapping', Proceedings *Meeting of the European Chapter of the Association for Computational Linguistics*, Utrecht, 287–297.

Roorda, Dirk: 1991, *Resource Logics: proof-theoretical investigations*, Ph.D. dissertation, Universiteit van Amsterdam.

Solias, T.: 1992, *Gramáticas Categoriales, Coordinación Generalizada y Elisión*, Ph.D. dissertation, Universidad Autónoma de Madrid.

---

[2] In view of space limitations the reader is invited to check the sequent calculus and proof net derivability of $R/((S{\uparrow}N)\odot I)$, N, $((((N\backslash S)/VP){\uparrow}N)\odot I)/N$, N, VP $\Rightarrow$ R (and underivability of N, $((((N\backslash S)/VP){\uparrow}N)\odot I)/N$, N, N, VP $\Rightarrow$ S) corresponding to the obligatory extraction (10), of N, $((N\backslash S)/N)/N$, $\{Q(S, N, S)|Q(N\backslash S, N, N\backslash S)\}$, N $\Rightarrow$ S corresponding to the quantification and reflexivisation (11), and of Q(S, N, S) $\Rightarrow$ Q(N\S, N, N\S).

Decomposing the progressive

Ralf Naumann* and Christopher Piñón*°
Universität Düsseldorf / Collegium Budapest°*

1. Introduction

The formal semantics of the *progressive aspect* is notoriously difficult to pin down, as a number of analyses in recent years attest (Dowty 1979:§3, Vlach 1981, Parsons 1990:§9, Bach 1986, Kearns 1991, Asher 1992, Landman 1992, Glasbey 1996, among others).[1] Broadly speaking, the progressive presents two sorts of problems: (*i*) (what we might call) the 'state-related problem' and (*ii*) (what Dowty calls) the 'imperfective paradox'. The state-related problem concerns the aspectually *stative* character of the progressive, the difference between 'progressive states' and 'ordinary states', the 'backgrounding' function of the progressive at the discourse level, etc. In contrast, the imperfective paradox is the problem that has attracted the most attention in the formal semantics literature: it consists in the observation that whereas the progressive of an activity expression entails the realization of the activity, the progressive of an accomplishment expression does not entail the realization of the accomplishment, as seen in (1a) and (1b), respectively.

(1) a. Rebecca was writing (when the computer crashed).
$\models$ Rebecca wrote. (activity)
b. Rebecca was writing the review (when the computer crashed).
$\not\models$ Rebecca wrote the review. (accomplishment)

For progressives of accomplishments such as that in (1b), the task is to say what it means for Rebecca's writing of the review to be 'in progress' when she has not yet written the review.

In this paper we propose a new analysis of the imperfective paradox. In doing so, we ignore the state-related problem of the progressive. The limitation is practical: we cannot cover the whole ground in a short paper, and the issues relating to the imperfective paradox seem to be clearer than those associated with the state-related problem. In any case, the limitation should not be taken to mean either that the state-related problem has a generally accepted solution (it does not) or that it is desirable to study the imperfective paradox in isolation from the state-related problem (arguably, it is not).

2. Issues

An inescapable fact about the progressive is that the events entailed are related in a direct way to the events denoted by the corresponding nonprogressive clause.[2] In (1a), this is obvious: we infer that Rebecca wrote and did not (say) eat or drink. Yet even in (1b), where the corresponding accomplishment is not entailed, it is at least true that Rebecca wrote part of the review. This observation might suggest that we can always use the verb of the corresponding nonprogressive clause to describe the events entailed by the progressive.[3] However, that we cannot always do so is shown by the examples in (2).

(2) a. Mary was making John a millionaire.
b. Rebecca was rescuing Peter.

[1]This work was supported by the *Deutsche Forschungsgemeinschaft* (*SFB* 282, *Teilprojekt* D3) (Naumann, Piñón) and by a fellowship from Collegium Budapest / Institute for Advanced Study (Piñón). I (Piñón) am grateful to Willi Geuder and the *Graduiertenkolleg* at *Universität Tübingen* for an invitation to lead an informal discussion on the progressive on 10 July 1997, an occasion which inspired me to begin thinking more earnestly about the topic. Comments welcome at: {*naumann, pinon*}*@phil-fak.uni-duesseldorf.de*

[2]Anticipating the analysis in section 3, we speak freely of events in describing the data.

[3]This observation is the springboard for *extensional* analyses of the progressive (Parsons 1990:§9, Kearns 1991:§5). Applied to the sentence in (1b), the strategy is to say that even unfinished reviews are reviews and therefore that the entailment in (1b) (despite initial appearances) is valid. However, since this strategy does not work for the examples in (2), an extensional analysis of the progressive is not tenable more generally.

In (2a), it is clear that Mary did something that could directly result in John's being a millionaire, but at the time that the progressive is uttered she need not have made him any money yet. Similarly, in (2b), although what Rebecca did could directly result in Peter's being rescued, she need not have accomplished any rescuing yet when the progressive is uttered. Examples of this kind provide evidence in favor of a *modal* analysis of the progressive: we can describe the events entailed by the progressive only by reference to their possible (but not necessarily actual) outcomes.

What unites the examples in (1) and (2) is that the events entailed by the progressive are possibly *parts* of events denoted by the corresponding nonprogressive clauses. In (1), since it is reasonable to suppose that any writing event has writing events as parts, we can infer from the use of the progressive that there is a writing event with Rebecca as its agent. In (2), although the events entailed are not semantically determined in this way, it is still reasonable to think that they could be parts of those denoted by the corresponding nonprogressive clauses. After all, not anything goes: an event in which Mary swims in the local pool would not normally verify the truth of (2a), precisely because it is difficult to see how her swimming could be part of an event in which she makes John a millionaire. However, if her swimming in the local pool somehow induced wealthy investors to invest in John's company, such an event could support the truth of (2a). A similar semantic indeterminacy arises in (2b): the events entailed are possibly parts of rescuing events, but the range of events that count as parts of rescuing events is not semantically fixed.

In any case, an analysis of the progressive requires more than a little modality and an appeal to parts: this is evident when the progressive is used in assertions that are difficult to evaluate as true or false. Imagine a situation in which a coin is flipped up into the air: if the odds are even, it would be infelicitous to utter one of the sentences in (3) (or its negation, for that matter). Intuitively, it is difficult to see why the coin is or is not coming up heads (tails)—since we do not have any reason for favoring the one outcome over the other, use of the progressive is odd.[4]

(3) a. The coin is (isn't) coming up heads.
    b. The coin is (isn't) coming up tails.

Notice that the issue here is not what counts as part of an event in which the coin comes up heads (tails), for *that* is fairly clear: the coin follows a trajectory through space, it is on its descent, it has already fallen part of the way down. The problem, rather, is that use of the progressive appears to force us into accepting a kind of weak determinism with respect to the possible outcome which we are not inclined to accept in this situation, precisely because—as far as we can tell—the odds are even.

This phenomenon arises in other examples as well. Suppose that Rebecca draws a straight line on a piece of paper and at that point we utter one of the sentences in (4) (or its negation). Intuitively, unless we assume something about Rebecca's intentions, these assertions are difficult to evaluate as true or false: since a straight line could be part of either a square or triangle, how do we decide which of the two she is drawing? Again, we simply do not have any reason, given what we see, for favoring the one outcome over the other.

(4) a. Rebecca is (isn't) drawing a square.
    b. Rebecca is (isn't) drawing a triangle.

Suppose, however, that we believe that Rebecca intends to draw a square: then it is much easier to evaluate the (positive) sentence in (4a) as true and the (positive) one in (4b) as false. Intuitively, this is because our believing that Rebecca intends to draw a square is enough to satisfy the kind of weak determinism that use of the progressive appears to demand: we should have grounds for favoring the possible outcome described over other possible outcomes. Similarly, if we believe that Rebecca intends *not* to draw a

[4]Examples like those in (3) originally motivated Dowty's (1979:147–148) appeal to *inertia worlds*. Dowty points out that such sentences turn out to be true in his earlier analysis (without inertia worlds), which is a counterintuitive result, and that the introduction of inertia worlds makes them come out as false, which is a step better. Our view is that such sentences tend to lack a true value in most circumstances and in section 3 we analyze them as involving a presupposition failure.

square, then the negative sentence in (4a) appears to be true. In this case, though, it is still difficult to evaluate the assertions in (4b) as true or false, because our belief of Rebecca's intending not to draw a square leaves it of course open whether she is drawing a triangle.

While intention plays an important role in the semantics of the progressive, there is more to the story. The assertions in (5) seem to be false, even if we are willing to believe that Rebecca intended to swim across the Atlantic and that Peter intended to wipe out the Russian army. Intuitively, the problem is that we also believe that Rebecca and Peter, as ordinary human beings, were not able to accomplish such feats, no matter what their intentions may have been.

(5) a. Rebecca was swimming across the Atlantic.
b. Peter was wiping out the Russian army.

The interesting twist about such examples is that their truth value depends in part on the utterance time. In (5a), suppose that Rebecca's swim was videotaped. If we were on location at the time when she had swum the first kilometer, we would most likely have denied the assertion in (5a) then. If, however, it later turns out that Rebecca managed to accomplish what we took to be humanly impossible and we are watching the first kilometer of her swim on video, we would most likely evaluate the assertion in (5a) as true now. Observe, crucially, that we need not assume that Rebecca's abilities actually changed during the swim: Rebecca may have had superhuman swimming abilities all along, but we believed (mistakenly, it turned out) that she did not have such abilities. A similar scenario could be constructed for the example in (5b) to make the same point.

Having the ability to do something should be kept distinct from the possibility (under the circumstances) of exercising that ability. In (5), we judge the assertions as false because we believe that the respective agents did not have the described abilities. Clearly, if one does not have a particular ability, then there is no possibility of exercising that (nonexistent) ability. But having a particular ability does not mean that it is always possible to exercise it, because incidental factors may prevent one from doing so.

With this in mind, consider the sentences in (6), which we are inclined to accept as true, assuming the described situations. In (6a), if the minefield had a fair number of mines and Mary did not know their exact whereabouts, the chances were slim that she would manage to run across. Likewise, in (6b), if there were many speeding trucks on the road, then the chances were not good that Peter would succeed in walking across, especially if he were not careful. However, despite the pessimistic outlooks involved, we are more inclined to evaluate the assertions in (6) as true than those in (5).

(6) a. Rebecca was running across the minefield.
b. Peter was walking across the road with speeding trucks.

The difference between the situations described in (5) and (6) turns on ability. If Rebecca wants to run across the minefield successfully, then she should know where the mines are so that she can avoid them. But beyond this, the ability to run across a minefield is no different than the ability to run across a field, and we believe that Rebecca is able to run across a field. Similarly, if Peter wants to walk across the road with speeding trucks successfully, he should take utmost care and wait for a maximally large break in the traffic, but other than this, we do not doubt that he is able to walk across the road. In neither case does Rebecca or Peter have to acquire an ability that they do not already have. This conclusion is consistent with the possibility that Rebecca or Peter will not be able to exercise their respective abilities under the circumstances.

In (5), the matter is different: here we believe that Rebecca is not able to swim across the Atlantic and that Peter is not able to wipe out the Russian army. Swimming across the Atlantic is not like swimming across a lake: a new ability is required to accomplish the former. Similarly, wiping out the Russian army is not like wiping out a few gangsters: two different abilities are at issue. Even if the circumstances are extremely favorable, humans are not able to do such things single-handedly.

The issues touched upon in this section concerned modality, parts of events, belief, intention, and ability. In the next section, we show how these notions figure in a semantics for the progressive.

3. Analysis

The hallmark of the analysis to follow is that the meaning of the progressive is *decomposed* into four independently needed notions: *realization, belief, ability*, and *intention*. Ability and intention, in contrast to realization, are *relativized* to the belief of the speaker at the utterance time. Working in tandem, these four notions yield a characterization of what it means for an event of a particular type to be 'in progress'.

For reasons of convenience and perspicuity, we present the analysis in (what we take to be) a familiar and transparent logic, essentially that of a *many-sorted type theory* (cf. Gallin 1975:§8, Gamut 1991:§5.8). In particular, we postulate four sorted domains: worlds, ordinary individuals, events, and times. Accordingly, the logic has inventories of variables and constants of different logical types that have these sorts of objects in their extensions. Characteristic of many-sorted type theory is that *s*, like *e* and *t*, is a type: consequently, variables for worlds (w, w', ...) appear in the object language and may be quantified and abstracted over. Note that constants whose extension varies from world to world are equipped with a (free) variable of type *s*. We assume that the progressive is represented by an operator whose logical type is that of a modifier of event predicates (i.e., $\langle\langle e, t\rangle, \langle e, t\rangle\rangle$), which presupposes that verbs are analyzed as predicates with an event argument, as is usual in event semantics.

We begin with the role of *realization*: if an event *e* of type *P* is in progress, then *e* is a partial realization of an event *e'* of type *P*. Invoking existential quantification over worlds and a *part relation* on events, the latter clause may be reformulated as 'then there is a world *w* in which *e* is part of an event *e'* such that *e'* is an event of type *P*', as formalized in (7), where '$\sqsubseteq_w$' denotes the (improper) part relation at world *w*.

(7) $\text{Real}(e, P) \triangleq \exists w \exists e'[e \sqsubseteq_w e' \wedge P(w)(e')]$ (*e* is a partial realization of *P*)

Observe that, due to the existential quantification over worlds, it is left open whether there is such an event *e'* in the actual world.

Applied to the sentence in (1b), realization requires that the event in progress be possibly part of one in which Rebecca writes the review. Coupled with a constraint stating that parts of an event in which Rebecca writes the review are events in which she writes part of the review, we rule out the possibility that the event in progress in (1b) is one in which Rebecca (say) eats part of an apple, for no event in which she eats part of an apple is possibly part of one in which she writes the review. Realization applies to the examples in (2) with equal force, though here we have the additional problem of having to decide what counts as parts of an event in which Mary makes John a millionaire, etc., which depends on considerable extralinguistic knowledge, as claimed in the previous section.

Realization is subject to a *presupposition* requiring that the speaker believe at the utterance time that the event in progress is *not* the partial realization of two *incompatible* event types, i.e., the presupposition demands that the speaker believe that the event in progress is *not* wildly *indeterministic* with respect to its event type. The *compatibility relation* between event types is defined in (8a): types *P* and *P'* are compatible just in case there is a world *w* in which an event *e* is of both types. The presupposition is then formulated in (8b): if event *e* is a partial realization of type *P* in the actual world, then the speaker x_{Spr} believes at the utterance time t_{Utt} in world *w* that any type *P'* that *e* is a partial realization of is compatible with *P*.

(8) a. $\text{Comp}(P, P') \triangleq \exists w \exists e[P(w, e) \wedge P'(w, e)]$ (*P* and *P'* are compatible)
b. $\text{Real}(e, P) \rightarrow \text{Bel}(w, t_{Utt}, x_{Spr}, \lambda w'[\forall P'[\text{Real}(e, P') \rightarrow \text{Comp}(P, P')]])$
(presupposition: speaker's belief in compatibility of partially realized event types)

Observe that the propositional argument of Bel is represented by abstraction over possible worlds (extensionally, the set of worlds *w'* in which it is true that if *e* is the partial realization of a type *P'*, then the types *P* and *P'* are compatible).

The presupposition in (8b) is motivated by examples like those in (3) and (4). In (3), since the speaker does not believe that the event type in which a coin comes up heads is compatible with the event type in which the same coin comes up tails, the presupposition in (8b) fails to be satisfied. Before the coin has landed, the speaker believes that the event in progress may be a partial realization of either event type and has no grounds for favoring the one over the other. Similarly, in (4), if that the speaker does not assume anything about Rebecca's intentions, then there are no grounds for deciding between the possible realizations (a drawing of a square vs. a drawing of a triangle) of the event in progress, and so the presupposition in (8b) is once again not satisfied. Thus we claim that the difficulty of assigning a truth value to the sentences in (3) and (4) is due to a presupposition failure.

The role of *ability* is as follows: if the event in progress has an agent, then the speaker believes at the utterance time that the agent is *able* at the time of the event in progress to carry out an event of the type in question. In (9a), the predicate Able is defined as a four-place relation between a world w, a time t, an individual x, and an event type P (intuitively, x is able at t in world w to carry out P). According to the definition, x is able at t in world w to carry out P just in case there is a world w' in which x is the agent of an event e of type P and the time of e temporally overlaps with t and w' is compatible with the abilities of x at t in w (where '$\circ_w$' denotes *temporal overlap* at world w and 'τ' denotes the *temporal trace function* for events, the value of which when applied to a particular event is assumed to be rigid). Note that $R_{Ability}$, which we take as primitive, is a kind of *accessibility relation* among worlds: for a world w, a time t, and an individual x, $R_{Ability}$ relates those worlds w' that are compatible with the abilities of x at t in w. The embedding of Able under Bel is given in (9b).

(9) a. $\text{Able}(w, t, x, P(w)) \triangleq$
$$\exists w'\exists e[P(w', e) \wedge \text{Agent}(w', e, x) \wedge t \circ_w \tau(e) \wedge R_{Ability}(w, t, x, w')]$$
(x is able at time t in world w to carry out an event of type P)

b. $\text{Bel}(w, t_{Utt}, x_{Spr}, \lambda w'[\text{Able}(w', t', y, P(w'))])$
(speaker's belief that agent is able to carry out P)

Examples like those in (5) motivate the inclusion of the speaker's belief of the agent's ability in the meaning of the progressive. Since we generally do not believe that human beings are single-handedly able to swim across the Atlantic or to wipe out the Russian army, we tend to judge the assertions in (5) as false. And this is so even if the events in progress satisfy Real in (7), for it is logically possible that Rebecca or Peter will succeed, but we clearly do not believe that such worlds are compatible with the abilities of Rebecca or Peter at the time of the event in progress in the actual world. Note, crucially, that since the speaker's belief of the agent's ability in (9b) is dependent on the utterance time, if it turns out that Rebecca does in fact succeed in swimming across the Atlantic, we might revise our beliefs about her abilities and later evaluate the assertion in (5a) as true.

Finally, we address the role of *intention*: if the event in progress has an agent, then the speaker does *not* believe at the utterance time that the agent intends at the time of the event in progress *not* to carry out an event of the type in question. In (10a), the predicate Intend is defined as a four-place relation between between a world w, a time t, an individual x, and the set of worlds w' in which x is the agent of an event e of type P and the time of e temporally follows t (intuitively, x intends at t in world w to carry out an event e of type P). According to the definition, Intend applies just in case in all worlds w' that are compatible with the intentions of x at t in w, x is the agent of an event e of type P and the time of e temporally follows t (where '$<_w$' denotes *temporal precedence* at world w). Again, the relation $R_{Intention}$ is a kind of accessibility relation among worlds: for a world w, a time t, and an individual x, $R_{Intention}$ relates those worlds w' that are compatible with the intentions of x at t in w. The speaker's *not* believing that the agent intends *not* to carry out an event e of type P is represented in (10b).

(10) a. $\text{Intend}(w, t, x, \lambda w'[\exists e[P(w', e) \wedge \text{Agent}(w', e, x) \wedge t <_w \tau(e)]]) \triangleq$
$$\forall w''[R_{Intention}(w, t, x, w'') \rightarrow \exists e[P(w'', e) \wedge \text{Agent}(w'', e, x) \wedge t <_{w''} \tau(e)]]$$
(x intends at time t in world w to carry out an event e of type P)

b. $\neg$Bel(w, t_{Utt}, x_{Spr}, λw'[Intend(w', t', y,
λw''[$\neg\exists$e[P(w'', e) $\wedge$ Agent(w'', e, y) $\wedge$ t$<_{w''}\tau$(e)]])])
(speaker's not believing that agent intends not to carry out an event *e* of type *P*)

The condition in (10b) is motivated by examples like those in (4). In (4a), suppose that we believe that Rebecca intends not to draw a square: the (positive) sentence is then false, because the condition in (10b) is not satisfied. This belief about Rebecca may arise because we also believe that she intends to draw a triangle—presumably Rebecca's intention to draw a triangle at that moment is incompatible with an intention to draw a square at the same time. In contrast to ability, it is arguably too strong to require that the speaker believe that the agent intends to carry out *P*, because the (positive) sentence in (4a) may be true even if the speaker believes that Rebecca does not intend to draw a square (note, moreover, that the agent's *not intending* to carry out *P* does not entail the agent's *intending not* to carry out *P*).

In sum, we define the assertive content of the progressive operator Prog as in (11), where 'End' denotes that (modally rigid) function which yields the final instant of intervals. Since not all events have agents, the speaker's belief of the agent's ability to carry out *P* and the speaker's not believing that the agent intends not to carry out *P* are relevant only when the event in progress has an agent. Although the presuppositional content of Prog as stated in (8b) is not officially represented in (11), it is nonetheless vital to the analysis of the progressive, as we have argued.

(11) Prog(w, t_{Utt}, x_{Spr}, e, P(w)) $\triangleq$ (assertive content of the progressive)
Real(e, P) $\wedge$
$\forall$y[Agent(w, e, y) $\rightarrow$
Bel(w, t_{Utt}, x_{Spr}, λw'[Able(w', End(τ(e)), y, P(w'))]) $\wedge$
$\neg$Bel(w, t_{Utt}, x_{Spr}, λw'[Intend(w', End(τ(e)), y,
λw''[$\neg\exists$e[P(w'', e) $\wedge$ Agent(w'', e, y) $\wedge$ End(τ(e))$<_{w''}\tau$(e)]])])]

Our analysis is at once radical and conservative when compared with previous analyses of the progressive. It is radical in that it makes the roles of ability, intention, and the speaker's belief more explicit than in any other analysis that we are aware of. Also, the idea that the progressive involves a presupposition enables us to account for cases in which assertions lack a truth value—a phenomenon not treated by previous analyses. At the same time, the analysis is conservative in that it does not appeal to otherwise unmotivated and unanalyzed notions such as *inertia worlds* (Dowty 1979) or *reasonable options* (Landman 1992). Moreover, it suggests that the semantics of the progressive *per se* does not require the adoption of a *default logic* (Asher 1992) or the resources of *channel theory* (Glasbey 1996).

References

Asher, Nicholas. 1992. A default, truth conditional semantics for the progressive. *Linguistics and Philosophy* 15: 463–508.

Bach, Emmon. 1986. The algebra of events. *Linguistics and Philosophy* 9: 5–16.

Dowty, David. 1979. *Word meaning and Montague Grammar: the semantics of verbs and times in Generative Semantics and in Montague's PTQ*. Dordrecht: D. Reidel Publishing Company.

Gallin, Daniel. 1975. *Intensional and higher-order modal logic* (= *North-Holland mathematics studies*; 19). Amsterdam: North-Holland Publishing Company.

Gamut, L. T. F. 1991. *Intensional logic and logical grammar* (= *Logic, language, and meaning*, v. 2). Chicago: The University of Chicago Press.

Glasbey, Sheila. 1996. The progressive: a channel-theoretic analysis. *Journal of Semantics* 13: 331–361.

Kearns, Katherine Susan. 1991. *The semantics of the English progressive*. Cambridge, MA: MIT disseration.

Landman, Fred. 1992. The progressive. *Natural Language Semantics* 1: 1–32.

Vlach, Frank. 1981. The semantics of the progressive. *Tense and aspect* (= *Syntax and semantics*; 14), ed. P. J. Tedeschi and A. Zaenen, 271–292. New York: Academic Press.

The Dynamics of Discourse Situations (Extended Abstract)

Massimo Poesio Reinhard Muskens

1 Introduction

The shared 'conversational score' in a conversation does not consist only of information about the propositional content of utterances. The participants in a conversation also share information about whose turn it is to speak, how what is being said fits in within the structure of the rest of the conversation, and whether what has been said needs acknowledging (Clark, 1996). Thus, the typical conversation consists not only of utterances performed to assert or query a proposition, but also of utterances whose role is to acquire, keep, or release a turn, to signal how the current utterance relates to what has been said before, or to acknowledge what has just been uttered (Poesio and Traum, 1997; Ginzburg, 1997). The linguistic tools used for these purposes include cue phrases such as *so* or (one sense of) *okay*; keep-turn signals such as *umm* or *wait*; and grounding signals such as *okay* again, *right* or *huhu*. Bunt (1995) proposed for these utterances the term DIALOGUE CONTROL ACTS.

Specifying the meaning of these expressions is a fundamental problem in the semantics of dialogues. In keeping with the assumptions of theories of the common ground such as DRT or DPL (Kamp and Reyle, 1993; Groenendijk and Stokhof, 1991), we are going to identify the meaning of an utterance with the way it modifies the conversational score; on the other hand, the simplest (and arguably most natural) way of characterizing the meaning of dialogue control acts is in terms of a theory in which the conversational score is seen as a record of the discourse situation, or at least of the speech acts that have been performed. The problem we address in the paper is how to reconcile a model of the conversational score in which the update potential of these utterances can be specified with current views on how discourse entities become possible antecedents for anaphoric expressions.

2 The Basic Idea

A Simple Characterization of Discourse Situations

The effect of dialogue control acts is most naturally characterized in terms of a speech act-based theory. As a result, the problem of specifying the meaning of the expressions used to perform dialogue control acts was addressed in (Poesio and Traum, 1997) by proposing that the conversational score consists of a record of the speech acts performed during the conversation, i.e., a stripped-down characterization of what is called the DISCOURSE SITUATION in Situation Semantics (Barwise and Perry, 1983). Furthermore, the approach adopted in (Poesio and Traum, 1997) was to continue using the tools introduced in DRT to specify the content of the conversational score, treating speech acts just like any other ordinary event. For example, whereas the ordinary DRT construction algorithm would assign to the text in (1) a DRS along the lines of (2), we hypothesize that the common ground in a conversation is more like (3), where we have adopted the syntax from (Muskens, 1995).

(1) A: There is an engine at Avon.
B: *It* is hooked to a boxcar.

(2) $[x,w,y,u,s,s'|\mathbf{engine}(x), \mathbf{Avon}(w), s : \mathbf{at}(x,w), \mathbf{boxcar}(y), s' : \mathbf{hooked\text{-}to}(u,y), u = x]$

(3) $[ce1,ce2|\ ce1 : \mathbf{inform}(A,B,[x,w,s|\ \mathbf{engine}(x), \mathbf{Avon}(w), s : \boxed{\mathbf{at}(x,w)}\ ]),$
$ce2 : \mathbf{inform}(B,A,[y,u,s'|\ \mathbf{boxcar}(y), s' : \boxed{\mathbf{hooked\text{-}to}(y,u)}, u = x\ ])]$

(3) records the occurrence of two CONVERSATIONAL EVENTS *ce1* and *ce2*, both of them **informs** (we assume the speech act classification scheme from (Poesio and Traum, 1997)), whose propositional content are the DRSs specifying the interpretation of the two utterances in (1). As in (Kamp and Reyle, 1993; Muskens, 1995), a Davidsonian treatment of events is assumed, in which each event- or state-describing predicate **p** such as **hooked-to** or **inform** has an additional argument for the event (or state). We also follow the convention in (Kamp and Reyle, 1993) of writing $e : \mathbf{p}(x,y)$ rather than $\mathbf{p}(x,y,e)$ for these predicates.

The hypothesis that the shared information about the discourse situation also takes the form of a DRS has the advantage of simplicity, in that the same conceptual and technical tools can be used to characterize both the discourse situation and the content of utterances; but the real reason for adopting characterizations of the discourse situation along the line of (3) is that we can then use the accessibility mechanisms from DRT to describe references to aspects of the discourse situation. For example, treating speech acts in the same way that events are treated in DRT means that we can explain anaphoric reference to speech acts just as anaphoric reference to events is treated in DRT. Such references can be explicit or implicit, just as in the case of reference to events; both forms force us to assume that speech acts are explicitly recorded in the conversational score. An example of explicit reference is example (4a) (from (Webber, 1991)): given our hypothesis that the conversational score is like in (3), the reference to the first speech act in (4a) can be assigned the interpretation in (4b). We discuss examples of implicit references to speech acts and other cases of reference to the content of the discourse situation below.[1]

(4) a. A: The combination is 1-2-3-4.
B: Could you repeat *that*? I didn't hear *it*.

b. $[ce1,ce2,ce3|\ ce1 : \mathbf{inform}(A,B,[x|\mathbf{combination}(x), x = 1\text{-}2\text{-}3\text{-}4\ ]),$
$ce2 : \mathbf{request}(B,A,[e,u|\ e : \mathbf{repeat}(A,u), u = ce1]),$
$ce3 : \mathbf{inform}(B,A,[|\neg\ [e',u'|\ e' : \mathbf{hear}(B,u'), u' = ce1]])\ ]$

We adopt Muskens' reformulation of DRT in (Muskens, 1995), in which the expressions of DRT are interpreted in a typed logic which, besides types for eventualities and times, provides a type *s* for assignments ('states'); discourse entities are then treated as functions from assignments to values. Muskens introduces a relation $i[u_1, \ldots, u_n]j$ that holds between states i and j if j differs from i at most over the values assigned to discourse entities $u_1, \ldots, u_n$:

- $i[u_1, \ldots, u_n]j$ is short for $\forall v\ (u_1 \neq v \wedge \ldots \wedge u_n \neq v) \rightarrow (v(i) = v(j))$, and $i[]j$ is short for $\forall v v(i) = v(j)$.

DRSs are then interpreted as relations between assignments, and conditions as functions from assignments to truth values. The mapping from DRS expressions into type theory is provided by a translation function $\circ$ whose clause for DRSs, for example, is as follows:

$$[\mathrm{u}_1, \ldots, \mathrm{u}_n \mid \phi_1, \ldots, \phi_m]^\circ \quad = \quad \lambda i \lambda j i[u_1, \ldots, u_n]j \wedge \phi_1{}^\circ(j), \ldots, \phi_m{}^\circ(j)$$

(Muskens, 1995) does not make explicit provision for DRS occurring as arguments of extra-logical predicates, but the standard accessibility conditions of DRT can be added by requiring that the value of a discourse entity u be preserved within an embedded DRS K. This can be done by revising first of all the definition of the function $\circ$ translating DRS constructs into type theory to make it depend on the set of accessible discourse entities D:

$$[\mathrm{u}_1, \ldots, \mathrm{u}_n \mid \phi_1, \ldots, \phi_m]^\circ_D = \lambda i \lambda j i[u_1, \ldots, u_n]j \wedge \phi_1{}^\circ_{D \cup \{u_1, \ldots, u_n\}}(j), \ldots, \phi_m{}^\circ_{D \cup \{u_1, \ldots, u_n\}}(j)$$

[1] Subordination relations between utterances such as those assumed in Grosz and Sidner's theory (Grosz and Sidner, 1986) or in SDRT (Asher, 1993) get interpreted as relations among speech acts–e.g., we can say that ce2 elaborates ce1. See below.

and then making the translation of DRSs embedded in conditions depend on the set of accessible discourse entities:

$$\mathbf{p}(\overline{x}, [u_1, \ldots, u_n \mid \phi_1, \ldots, \phi_m], \overline{y})\circ_D =$$
$$\lambda i \mathbf{p}(\overline{x}\circ_D, \lambda j \lambda k i \subseteq_D j \wedge j[u_1, \ldots, u_n]k \wedge \phi_1 \circ_{D\cup\{u_1,\ldots,u_n\}} (k), \ldots, \phi_m \circ_{D\cup\{u_1,\ldots,u_n\}} (k), \overline{y}\circ_D)$$

where we have used the notation $i \subseteq_D j$ to indicate that all the discourse entities in D assign the same value to i and j. This is sufficient to ensure that in (4b), the discourse entity *ce1* gets the appropriate value in the DRSs specifying the contents of speech acts *ce2* and *ce3*.

How Utterances Update the Discourse Situation

The advantage of adopting a compositional version of DRT is that we need not assume that (3) is constructed all at once; instead, we can hypothesize that it is built compositionally by concatenating the interpretations obtained separately for the two utterances, as in (5).

(5) [*ce1*| *ce1* : **inform**(*A*,*B*,[*x*,*w*,*s*|**engine**(*x*), **Avon**(*w*), *s* : [**at**(*x*,*w*)]])];
[*ce2*| *ce2* : **inform**(*B*,*A*,[*y*,*u*,*s'*| **boxcar**(*y*), *s'* : [**hooked-to**(*y*,*u*)], *u* = *x*])]

In turn, we can specify how these interpretations are constructed from the interpretations assigned to single utterances. We assume, as in (Poesio and Traum, 1997; Poesio, 1996) that the meaning of each word utterance specifies an update of the discourse situation, providing information about the occurrence of an utterance, about its syntactic classification, and its conventional meaning (i.e., its compositional meaning as specified in traditional formal semantics theories). An utterance of the noun *boxcar*, for example, results in the following update of the discourse situation, whereby the utterance of a new locutionary act *mce6* is recorded (we use the predicate **utter** to characterize locutionary acts), of syntactic category N and with semantic content λx *[|***boxcar**(*x*)*]*.

(6) *boxcar* ⇝ [*mce6*|*mce6* : **utter**(*A*,"*boxcar*"), **syn**(*mce6*) = *n*, **sem**(*mce6*) = λx *[|***boxcar**(*x*)*]*]

Within this view of utterance interpretation, the update of the conversational score originated by utterances that generate dialogue control acts is easy to specify: discourse markers such as *okay* or turn-taking signals such as *umm* will result in updates like (7) and (8), respectively, where we have adopted again the speech act taxonomy from (Poesio and Traum, 1997) (note also that utterances like *okay* include implicit references to previous speech acts).

(7) *okay* ⇝ [*ce1*|*ce1* : **accept**(*A*,*ce2*)]

(8) *umm* ⇝ [*ce2*|*ce2* : **keep-turn**(*A*)]

The price to pay when adopting this view of utterance meaning is that semantic composition cannot be specified anymore in terms of operations that manipulate semantic objects; instead, we are inevitably lead to an inferential characterization of semantic composition along the lines of that proposed in (Pereira, 1990), where the combination of utterances in larger utterances and the specification of the meaning of these larger utterances are provided by inference rules. The particular approach adopted here involves defeasible inferences over the DRS obtained by concatenating the updates resulting from the utterances of single words (Poesio, 1996). For example, the second sentence in (1) results in the following incremental updates of the discourse situation, one for each word utterance:

(9) [*mce1*|mce1:utter(a,"it"),cat(mce1)=pro, sem(mce1)=λp. [*u*|];p];
.....
[*mce5*|mce5:utter(a,"a"), cat(mce5)=det, sem(mce5)=λP. λp [*y*|];P(y);p];
[*mce6*|mce6:utter(a,"boxcar"),cat(mce6)=n, sem(mce6)=λx [|boxcar(x)]]

Again as in (Poesio and Traum, 1997; Poesio, 1996), we assume that syntactic composition and semantic interpretation are the result of an inference process that results in hypotheses about how 'lexical' utterances combine together in phrasal ones, and these in larger phrasal hypotheses. The conventional meaning of these larger events is derived by combining the conventional meaning of the constituent events. For example, such inferences may result in hypothesizing that *mce5* and *mce6* are subconstituents of a larger event *mce7* of syntactic type NP, with the result that the following update is inferred (we use the symbol $\uparrow$ to indicate sub-constituency).

(10) $[mce7 |\ mce7 : \textbf{utter}(A, \text{"a boxcar"}), \textbf{cat}(mce7) = np, \textbf{sem}(mce7) = \lambda p\ [y|];[|boxcar(y)];p,$
$mce5 \uparrow mce7, mce6 \uparrow mce7]$

3 The Dynamics of Discourse Situations

The problem with (3) is that the dynamic properties of DRT apparently get lost: e.g., what makes the discourse entity x in the third argument of *ce1* in (3) accessible from within the DRS in the content of *ce2*? We consider three hypotheses about how the dynamics might work in discourse situations.

3.1 First Hypothesis: Implicit Dynamics

The first, most conservative hypothesis is that accessibility depends on discourse structure, i.e., that the propositional contents of speech acts that are part of the same 'discourse segment' are implicitly related. Assuming a function **sp** from a speech act to the next speech act in the same discourse segment (corresponding to Grosz and Sidner's 'Satisfaction-Precedes' function), we could hypothesize that discourse entities became accessible because the following holds.[2]

AX-SP $\forall ce1, ce2, A, B, C, D, K1, K2, i$
$[ce1 : \textbf{p}(A,B,K1)]\circ(i) \wedge [ce2 : \textbf{r}(C,D,K2)]\circ(i) \wedge \textbf{sp}(ce1) = ce2 \rightarrow (\forall j, k K2(j,k) \rightarrow \exists l K1(l,j))$
[for **p**, **r** in {inform,suggest, ...}, K1 and K2 DRSs]

3.2 Second Hypothesis: Resource Situations

The second hypothesis we consider derives from the treatment of definite descriptions in (Poesio, 1993). The key observation from that work is that in spoken conversations people often have to deal with more than one 'topic situation', i.e., states of the world: e.g., two people who are developing a plan are simultaneously discussing the world as it is now (say, the current decoration of the kitchen), the actions in the plan, and the world as it will result from the plan (the kitchen after redecorating). All of these situations (that we will call RESOURCE SITUATIONS, as in Situation Theory) are part of the common ground: that is, in order to interpret a referring expression, the listener must identify the resource situation with respect to which that expression should be interpreted. Some resource situations (e.g., the situation representing the world around the speakers) are completely specified at the beginning of the conversation; other situations (e.g., the one representing the state of the kitchen at a given point of the planning) are 'constructed' in the course of the conversation. The second hypothesis we consider is that all reference in dialogue is mediated by resource situations.

For simplicity, we assume here that resource situations are just states in the sense of Compositional DRT, and that their content is specified by DRSs. We use the notation s::K to indicate that resource situation s is characterized by DRS K, with the following interpretation:

(11) $s :: K = \exists i K(i, s)$

According to the second hypothesis, the conversational score includes not only a record of the occurrence of speech acts, but also a record of the current resource situations. Thus, in the kitchen example, the conversational score will be as follows:

[2]This hypothesis about accessibility is similar to the one adopted in SDRT (Asher, 1993).

(12) [...*ce1, ce2*, ... *kitchen-sit*, *plan-sit1*, ...| ....
kitchen-sit :: *[x1,x2,...|***window***(x1),* **table***(x2),....]*
plan-sit1 :: *[y1,y2,...|***TV***(y1),,* **small-table***(y2),....]*]

We already noted that the resource situations may get updated by speech acts– for example, the situation resulting from the redecoration plan changes during the conversation. We are going to propose, more specifically, that these updates to the resource situations are specified by the content of the speech acts: for example, that in (1) we have an initial resource situation *rs1* for the world under discussion, and that the two speech acts extend this initial resource situation and the resource situation *rs2* resulting from this first update, respectively, as follows:

(13) [*ce1,ce2,rs1,rs2,rs3*|
ce1 : **inform**(*A,B*, [*x,w,s*| **engine**(*x*), **Avon**(*w*), *s* : **at**(*x,w*)](*rs1,rs2*)),
ce2 : **inform**(*B,A*, [*y,u,s'*| **boxcar**(*y*), *s'* : **hooked-to**(*u,y*), *u* = *x*](*rs2,rs3*))]

This hypothesis about the way the dynamics works (a variant of that proposed in (Poesio and Traum, 1997)) has the advantage that it gives us the tools to specify a theory of the process by which resource situations are chosen such as (Poesio, 1993); but in order for this implementation of the idea about resource situations to work, it is necessary to weaken Axiom 1 of Compositional DRT that specifies 'how many states' there must be in a model, so as to allow states to be the value of discourse entities while avoiding inconsistencies. The following version of the axiom only requires there to be an state j that differs from state i on the value of discourse entity (= object of type π) v for each object of type e.

AX1-WEAK $\forall i(state(i) \rightarrow \forall v_\pi, \forall x_e, \exists j(state(j) \wedge i[v]j \wedge v(j) = x))$

Anaphoric expressions such as pronouns and definite descriptions can now be taken to involve two presuppositional elements–the resource situation and the referent–rather than just one as in (Muskens, 1996):

(14) *the* ⇝ [*u*| *u* : **utter**(*A*,"*the*"), **cat**(*u*) = *det*,
sem(*u*) = $\lambda P \lambda Q \lambda i \lambda j \exists k(P(i,k)(X(R)) \wedge Q(k,j)(X(R)))$]

where R is an unbound discourse entity denoting the resource situation that specifies the value for the discourse entity X denoting the referent of the definite description. Depending on the value assigned to R different antecedents become available: thus in (12) a reference to an object in the kitchen-situation will be interpreted by fixing R to *kitchen-sit*, whereas a reference to an object in the plan situation will be interpreted by fixing R to *plan-sit1*. References to objects in the discourse situation will be interpreted by letting the inner abstraction in (14) bind R, i.e., by setting $R = i$.

3.3 Third Hypothesis: Propositional Discourse Entities

Finally, we consider the hypothesis that discourse entities become accessible because the DRSs specifying the contents of speech acts themselves become the values of discourse entities. That this is the case is shown by examples such as:

(15)
A: There is an engine at Avon.
B: Why is *that* important?

in which the antecedent of *that* appears to be 'the fact that the engine is at Avon', i.e., the content of the previous assertion by A (a DRS). But if we allow discourse entities denoting DRSs in the conversational score, the dynamics of the example (1) could be explained by assuming that the conversational score for (1) is as in (16):

(16) [*ce1,ce2,K,K',fspace0,fspace1,fspace2*| *fspace0* = [|],
K = [*x w s*| **engine**(*x*), **Avon**(*w*), *s* : **at**(*x,w*)],*ce1* : **inform**(*A,B,K*), *fspace1* = *fspace0;K*,

$K' = [y\ u\ s' |\ \mathbf{boxcar}(y),\ s' : \boxed{\mathbf{hooked\text{-}to}(y,u)},\ u = x\ ],$
$ce2 :\ \mathbf{inform}(B,A,K'), fspace2 = fspace1;K'\ ]$

According to this view of the dynamics, Grosz and Sidner's 'focus spaces' that, in the previous section, had been identified with situations, are actually DRSs. As in the previously examined hypothesis, the assumption here is that at any moment there is a current 'focus space', initially empty (*fs0*). The content of each complete speech act gets added to the conversational score (thus becoming available for reference), and the focus space is also updated by concatenating the previous focus space to the new content. These updates are not unlike those proposed in recent work on modal subordination by Geurts (1994). As in that work, it is necessary to impose constraints on the assignments in order to allow discourse entities to have propositions as values.

4 (Preliminary) Conclusions

We are at too early a stage to draw definite conclusions as to which of these three hypotheses about the dynamics of discourse situations fit better the facts. For the moment, we will just remark that of the three hypotheses, the first is the simplest; the third, while requiring the most complex modifications to the semantics, relies on mechanisms that have to be introduced anyway to deal with propositional reference; and the second gives us an easy way to explain how certain interpretive mechanisms work.

References

Asher, N. 1993. *Reference to Abstract Objects in English.* D. Reidel, Dordrecht.

Barwise, J. and J. Perry. 1983. *Situations and Attitudes.* The MIT Press.

Bunt, H. C. 1995. Dialogue control functions and interaction design. In R.J. Beun, M. Baker, and M. Reiner, editors, *Dialogue in Instruction.* Springer Verlag, pages 197–214.

Clark, H. H. 1996. *Using Language.* Cambridge University Press, Cambridge.

Geurts, B. 1994. *Presupposing.* Ph.D. thesis, University of Stuttgart.

Ginzburg, J. 1997. On some semantic consequences of turn-taking. In A. Benz and G. Jäger, editors, *Proc. of the Munich Workshop on Formal Semantics and Pragmatics of Dialogue.* University of Munich.

Groenendijk, J.A.G. and M.J.B. Stokhof. 1991. Dynamic Predicate Logic. *Linguistics and Philosophy,* 14:39–100.

Grosz, B. J. and C. L. Sidner. 1986. Attention, intention, and the structure of discourse. *Computational Linguistics,* 12(3):175–204.

Kamp, H. and U. Reyle. 1993. *From Discourse to Logic.* D. Reidel, Dordrecht.

Muskens, R. 1995. Tense and the logic of change. In U. Egli, P. Pause, C. Schwarze, A. von Stechow, and G. Wienold, editors, *Lexical Knowledge in the Organization of Language.* John Benjamins, Amsterdam / Philadelphia, pages 147–183.

Muskens, R.A. 1996. Combining Montague Semantics and Discourse Representation. *Linguistics and Philosophy,* 19:143–186.

Pereira, F. C. N. 1990. Categorial semantics and scoping. *Computational Linguistics,* 16(1):1–10, March.

Poesio, M. 1993. A situation-theoretic formalization of definite description interpretation in plan elaboration dialogues. In P. Aczel, D. Israel, Y. Katagiri, and S. Peters, editors, *Situation Theory and its Applications, vol.3.* CSLI, Stanford, chapter 12, pages 339–374.

Poesio, M. 1996. Ambiguity and underspecification. In M. Bierwisch, R. Blutner, and R. van der Sandt, editors, *From underspecification to interpretation: Proceedings of the Berlin Workshop on Underspecification.* IBM Deutschland: Working Papers of the Institute for Logic and Linguistics, Heidelberg.

Poesio, M. and D. Traum. 1997. Conversational actions and discourse situations. *Computational Intelligence,* 13(3):309–347.

Webber, B. L. 1991. Structure and ostension in the interpretation of discourse deixis. *Language and Cognitive Processes,* 6(2):107–135.

The Scope of Indefinites; a Deductive Account

Fabien R. Reniers
UiL-OTS, Utrecht

1 Introduction

A long standing problem in the area of scope is the exceptional scopal behavior of indefinites (cf. (Farkas 1981),(Fodor and Sag 1982),(Ruys 1992), (Kratzer 1995)). A recent development in this area of research is the use of choice functions for the interpretation of indefinites (cf. (Reinhart 1996), (Winter 1996)). In this paper we will contrast choice functions with a deductive account of binding. It is argued that a central feature of the choice functions approach — that is to banish movement of the indefinite's descriptive content beyond scope islands — leads to a fundamental problem in the semantics of indefinites. It turns out that this problem is tied up with in-situ interpretation.

Once we give up the idea of separating the descriptive content from its closure, the scope of indefinites can be accounted for in a uniform way; we will model both the scope of GQ's and indefinites in terms of one and the same type-logical connective. To this end we will put to use Moortgat's (1996) q(A,B,C)-connective for in-situ binding. The application of this connective to indefinites yields a system which has the expressivity of Reinhart's and Winter's choice-function mechanisms while generating 'classical' interpretations.

2 The embedding condition

Reinhart and Winter provide several choice function definitions. To set out the problem choice functions give rise to, we will use Reinhart's simple definition which captures the essence of more sophisticated definitions that take into account empty denotations and plurality.

(1) $CH = \{f_{<<e,t>,e>} | \forall P_{<e,t>}\ P \neq \emptyset_{<e,t>} \ \rightarrow\ P(f(P))\}$

The problem for choice functions is illustrated by the following sentences:

(2) a. It is not the case that every man$_i$ kissed [a woman he$_i$ knows].

b. It is not the case that every man kissed [a woman that some child knows].

The choice function mechanisms allow the following interpretations for the sentences above, since unselective binding may occur at each compositional sentence level:

(3) a. $\exists f\, CH(f) \ \wedge\ \neg[\forall x\, \text{Man}(x) \ \rightarrow \text{Kiss}(x, f(\lambda y.\, \text{Woman}(y) \wedge \text{Know}(x,y)))]$

b. $\exists f\, CH(f) \wedge \neg[\forall x\, \text{Man}(x) \ \rightarrow\ \exists g\, CH(g) \wedge \text{Kiss}(x, f(\lambda y.\, \text{Woman}(y) \wedge \text{Know}(g(\text{Child}), y)))]$

These readings yield the wrong semantics. Consider a model M in which there are two men and three women. Man$_1$ kissed and knows woman$_1$, man$_2$ kissed woman$_2$ and knows woman$_2$ and woman$_3$. Clearly, M does not satisfy sentence (2a). Reading (3a) however will be true in M: according to definition (1) there is a choice function f such that f(woman man$_1$ knows) = woman$_1$ and f(woman that man$_2$ knows) = woman$_3$. It should be noted that this problem is not restricted to bound pronouns[1]. A similar problem arises with indefinites that embed other indefinites. If *some child* takes narrow scope with respect to the universal, the complex indefinite must take narrow scope also. Interpretation (3b) is comparable to a classical interpretation in which the subject position of *knows* has become unbounded, as in (4).

(4) $\exists x\, [\text{Woman that } \mathbf{z} \text{ knows}](x) \ \wedge\ \forall y\, \text{Man}(y) \ \rightarrow\ \exists \mathbf{z}\, \text{Child}(\mathbf{z}) \wedge \text{Kissed}(y, x)$

[1]Winter observes a similar problem for sentences like *Every man loves a woman he knows*, and argues that this problem is due to the fact that the choice function is insensitive to the free variable in its argument. He suggests that the problem can be overcome by intensionalizing choice functions. However, this will not work for a negated sentence like (2a).

The origin of the problems in (3) is detected easily. The present choice function mechanisms are insensitive to a general embedding condition, blocking the nested dependencies of (5):

(5) $* \exists f \ \ldots \exists g \ \ldots f(\ldots g \ldots)$

This prompts the question whether we can repair the defects of the choice function mechanism by simply stipulating condition (5). We believe however that adding (5) as a stipulation is inconsistent with the philosphy of in-situ interpretation: what is shown by (5) is that the procedure of unselective binding can be performed adequately only if it has access to the information from the descriptive content. From a compositional point of view this means that the descriptive content should be available at the place of existential closure. The only way out of this dilemma is to *derive* condition (5) from the inherent properties of the choice function mechanism. In the next section we will discuss how a condition like (5) can be derived. It will turn out that deriving the embedding condition implies that the descriptive content should be accessible at the place of existential closure. Choice functions will be superfluous then.

3 Deriving the embedding condition

In order to derive condition (5) we will adopt Moortgat's type-logical connective for in-situ binding, which has the following rule of use:

(6)
$$\frac{\Delta[x : A] \Rightarrow t : B \qquad \Gamma[y : C] \Rightarrow u : D}{\Gamma[\Delta[z : q(A,B,C)]] \Rightarrow u[z(\lambda x.\, t)/y] : D}\ qL$$

As we noted before, the embedding condition is just the choice-function version of a general ban on free variables (compare (4)). It can be verified easily now that (6) rules out interpretations like (4) automatically. A complex NP like (7a) will be given the translation in (7b) (Note that generalized quantifiers are assigned the type q(np,s,s)). From (7b) it can be seen that the embedded q_2(np,s,s) must take scope first: in order to derive category N for q_1 we must get rid of q_2, which blocks the derivation. Since the connective which takes scope first gets wide scope automatically, patterns like (4) cannot occur.

(7) a. [DET [$_\mathrm{N}$ ... [DET N] ...]]

b. [q_1(np,s,s)/N [$_\mathrm{N}$ ... [q_2(np,s,s)/N N] ...]]

In a similar vein condition (5) can be derived. A straightforward (but wrong) translation of the choice function approach into Moortgat's system would amount to introducing a new type (f_{new}) for choice functions that integrates unselective binding in the lexical semantics of choice functions. This new type is defined as $f_{new} = q(f,s,s)$, where $f = np/n$, i.e. a choice function in the sense of (1). The semantics of f_{new} is $\lambda V_{<<<e,t>,e>,t>}.\, \exists f\, CH(f) \wedge V(f)$. It can be verified easily that this analysis does not yield condition (5), for in (8) nothing prevents that q_1 takes scope before q_2:

(8) a. [f_{new} [$_\mathrm{N}$ ... [f_{new} N] ...]]

b. [$q_1(f,s,s)$ [$_\mathrm{N}$ ... [$q_2(f,s,s)$ N] ...]]

It turns out that the origin of this defect is in the subcategorization frame of f_{new}; the subcategorization for N should be outside the q-connective. This amounts to a choice function definition $f_{new} = q(np,s,s)/N$ with semantics $\lambda P_{<e,t>}.\, \lambda Q_{<e,t>}.\, \exists f\, CH(f) \wedge Q(f(P))$. This yields the desired result:

(9)
$$\dfrac{\dfrac{\dfrac{\dfrac{\text{q}_2 \text{ restricts the bindingdomain } (\Delta) \text{ of q}_1}{q_1(np,s,s)/n, n/np, np, np \backslash s \Rightarrow s} \qquad np, (np \backslash s)/s, s \Rightarrow s}{np, (np \backslash s)/s, q_1(np,s,s)/n, n/np, q_2(np,s,s), np \backslash s \Rightarrow s}\ q_2L \qquad n \Rightarrow n}{np, (np \backslash s)/s, q_1(np,s,s)/n, n/np, q_2(np,s,s)/n, n, np \backslash s \Rightarrow s}\ /L}{John, thinks, f_{new}, friend-of, f_{new}, man, smiled \Rightarrow s}\ Lex$$

While the latter definition can derive (5), this modification to the choice function definition has rendered in-situ interpretation superfluous; the descriptive content (P) is accessible to the procedure of unselective binding, as can be witnessed from the semantics. What does this mean? Apparently, a choice function approach is feasible in that a deductive account of choice functions is able to generate at least the right set of interpretations. Nevertheless it seems that a choice function account which is consistent with (5) contradicts the philosphy of in-situ interpretation, namely a true separation between existential closure and descriptive content. While it cannot be excluded a priori that there are systems that unify both condition (5) and *true* in-situ interpretation, we believe the evidence above is at least suggestive. Apart from suggestive evidence the question arises as to whether choice functions are really necessary in the interpretation process. This question will be the topic of the next section.

4 Are choice functions necessary?

Are choice functions necessary? To answer this question it suffices to investigate which facts cannot be explained once we do away with choice functions. Obviously the idea of in-situ interpretation, which is central to the choice-function approach, cannot be explained under a deductive account. We believe however that there are good reasons to reject this idea. First, as we observed in the previous section, it seems that true in-situ interpretation cannot be given an appropriate formal treatment. Second, the idea underlying in-situ interpretation is that there may be no movement beyond islands. But how strong is this claim? Note that Moortgat's q-connective, which can be viewed of metaphorically as a general connective for movement (i.e. structural incompatibilities between syntax and semantics) applies to unselective binding as well. From a compositional point of view unselective binding is nothing more than 'movement beyond islands'. In other words, although we might get rid of moving the descriptive content, we cannot avoid that movement enters the system at another point in the derivation, i.e. in the procedure of unselective binding. Moreover, it seems to be incorrect to exclude all movement beyond islands. The projection problem of presuppositions formulated somewhat differently is just an instantiation of this kind of movement[2]:

(10) a. If John regrets that Peter is ill, I will be happy.

b. [Peter is ill $]_i$ and if John regrets that$_i$, I will be happy.

The interpretation of (10a) is expressed informally by (10b). What is shown is that the complement of *regret* is presupposed; it takes scope beyond islands.

Apart from in-situ interpretation, which we reject, we believe that choice functions do not have greater explanatory force than a classical semantics. Our deductive account below explains the observations that emerge from the literature on choice functions. These observations are:

1. Indefinites can take scope beyond islands.
   E.g. *John kissed every woman* [$_{\text{ISL}}$ *who knows*[*a student I know*]] can be understood with wide scope for the indefinite.

2. Indefinites can take scope at each sentence level (Intermediate scope).
   E.g. in *Every professor$_i$ will rejoice* [$_{\text{ISL}}$ *if* [*a student of his$_i$*] *cheats on the exam*] the indefinite can scope out of the antecedent of the conditional and remain in the scope of the universal.

3. Double scope: while indefinites can take scope beyond islands, their distributive properties are island-restricted.
   E.g. The sentence [$_{\text{ISL}}$ *If* [*three relatives of mine*] *die*], *I will inherit a house* cannot be interpreted as saying that each member of a specific set of three relatives of mine has the property of 'to die implies the inheritance of a house'.

[2]As Van der Sandt (1992) shows convincingly, presuppositions a) are part of the semantics and b) can be in the scope of a higher quantifier. Thus, it is conceivable that presuppositions can be given a formal treatment in Moortgat's system.

Let's have a look at how these observations follow from a deductive account. First, we will do away with choice functions and introduce a type shifter (analoguous to choice functions, which are invisible type shifters) *shift* into the process of interpretation[3]:

(11) *shift* : q(np,s,s)/n semantics: $\lambda P.\, \lambda Q.\, \exists x\, P(x) \wedge Q(x)$

This simple definition can explain observations 1) and 2) above. Scope beyond islands is trivial in that q(np,s,s) is insensitive to islands. Obviously this poses the question of how to account for phenomena that are island-restricted. We will assume that there are two types of q-connectives. One that is unrestricted, q(A,B,C), and another one which is restricted, say Qisl(A,B,C). Note that Reinhart and Winter *assume* that unselective binding is unconstrained and that quantifier raising is restricted within the boundaries of the island. Translated in terms of Moortgat's q-connective this simply comes down to the observation that q(A,B,C) should apply to unselective binding, and Qisl(A,B,C) to QR. So a choice-function approach is not less stipulative in this respect.

As for intermediate scope, it can be verified that definition (11) yields the desired result. As can be observed in (6) the binding domain (Δ) of q(np,s,s) can be any sentence.

This leaves us with Winter's double scope observation. Since this observation comprises plurality, definition (11) is not appropriate. The following modification will do:

(12) *shift* : q(GQ,s,s)/n semantics: $\lambda P.\, \lambda R_{<ett,t>}.\, \exists x\, P(x) \wedge R([\lambda Q.\, Q(x)])$
GQ : Qisl(np,s,s)

The present definition of *shift* does the same job as Winter's choice functions, which return collective quantifiers. Operational distributivity is modelled by a distributivity operator (say $distr = GQ/GQ = Qisl(np,s,s)/Qisl(np,s,s)$) which we assign the semantics of Winter's distributivity operator D:

(13) $$D_{<ett,ett>} = \lambda G_{<et,t>} \begin{cases} D'(\mathrm{x}) & \text{if there is a unique plural individual } x \text{ such that: } G = \lambda \mathrm{P}.\, \mathrm{P}(x) \\ \mathrm{G} & \text{otherwise} \end{cases}$$

$$\mathrm{D'}_{<e,ett>} = \lambda x.\, \lambda \mathrm{P}.\, \forall y\, \Pi(y)(x) \rightarrow \mathrm{P}(y)$$

Where $\Pi(y)(x)$: y is an atomic individual of plural individual x.

In this way double scope is obtained. While *shift* takes care of scope beyond islands as far as collective quantifiers are concerned, the local application of *distr* to these quantifiers yields a distributive quantifier, which may take its scope only within the boundaries of the island.

5 Imposing island constraints on q(A,B,C)

In the previous section we introduced Qisl(A,B,C), an island restricted q-connective. In this section we will discuss briefly how this connective is defined. To define Qisl we will have to make some assumptions about how islands are modelled in a multimodal framework A simple way to do this, is by introducing an island mode *isl*, as in (14b).

(14) a. A man [$_{\text{ISLAND}}$ who everyone saw]

b. $(A \circ (man \circ_{isl} (who \circ (everyone \circ saw))))$

[3] *Shift* serves merely to stay as close as possible to the choice function approach. Nothing hinges on this invisible type shift operation; it can be built into the lexical entry of numerals.

With this assumed, a slight modification to Moortgat's original account yields q(A,B,C) and Qisl(A,B,C)[4]:

(15) Modes of composition:

f, r	:	free and restricted wrapping mode ($\bullet_f$, $\bullet_r$)
i	:	phrasal composition, we will write $\circ, \backslash, /$ for $\circ_i, \backslash_i, /_i$.
isl	:	island mode ($\circ_{isl}$)

(16) Structural postulates:

$$\begin{array}{lrcll}
(P0) & \Diamond A & \leftrightarrow & A \bullet_M t & (P0') \quad \text{for } M \in \{f, r\} \\
(P1) & (A \bullet_M B) \circ C & \leftrightarrow & A \bullet_M \Diamond_l (B \circ C) & (P1') \quad \text{for } M \in \{f, r\} \\
(P2) & A \circ (B \bullet_M C) & \leftrightarrow & B \bullet_M \Diamond_r (A \circ C) & (P2') \quad \text{for } M \in \{f, r\} \\
 & & & & \\
(Isl) & A \circ_{isl} (B \bullet_f C) & \leftrightarrow & B \bullet_f (A \circ_{isl} C) & (Isl')
\end{array}$$

(17) Decomposition of an island-free and island-restricted q:

$$q(A, B, C) \;=\; \Diamond(C/_f(\Box A \backslash_f B)) \qquad Qisl(A, B, C) \;=\; \Diamond(C/_r(\Box A \backslash_r B))$$

As can be seen from the definitions above there are two wrapping modes, a restricted and unrestricted one. Our modification to Moortgat's account is only with respect to the application of (P0)-(P2) to *both* wrapping modes. Furthermore, we included an island-postulate that 'lifts' the free wrapping mode across islands. Below we will give a sample derivation of double scope on the basis of the sentence *John thinks three men smiled.* To keep the derivation simple we will assume that *thinks* projects an island.

(18) a. Semantics: $\exists x\, \mathrm{Three(Men)}(x) \wedge \mathrm{Think}(j, D'(x)(\mathrm{Smile}))$.

b.

$$\begin{array}{ll}
\qquad\qquad (18c) & \\ \hline
John \circ (thinks \circ_{isl} ((distr \circ GQ) \circ smiled)) \Rightarrow s & Lex \\ \hline
John \circ (thinks \circ_{isl} ((distr \circ \Diamond\Box GQ) \circ smiled)) \Rightarrow s & \Box L \\ \hline
John \circ (thinks \circ_{isl} ((distr \circ (\Box GQ \bullet_f t)) \circ smiled)) \Rightarrow s & P0' \\ \hline
John \circ (thinks \circ_{isl} ((\Box GQ \bullet_f \Diamond_r(distr \circ t)) \circ smiled)) \Rightarrow s & P2' \\ \hline
John \circ (thinks \circ_{isl} (\Box GQ \bullet_f \Diamond_l(\Diamond_r(distr \circ t) \circ smiled))) \Rightarrow s & P1' \\ \hline
John \circ (\Box GQ \bullet_f (thinks \circ_{isl} \Diamond_l(\Diamond_r(distr \circ t) \circ smiled))) \Rightarrow s & Isl' \\ \hline
\Box GQ \bullet_f \Diamond_r(John \circ (thinks \circ_{isl} \Diamond_l(\Diamond_r(distr \circ t) \circ smiled))) \Rightarrow s & P2' \\ \hline
\Diamond_r(John \circ (thinks \circ_{isl} \Diamond_l(\Diamond_r(distr \circ t) \circ smiled))) \Rightarrow \Box GQ \backslash_f s \quad {\backslash_f R} \qquad s \Rightarrow s & \\ \hline
(X \bullet_f \Diamond_r(John \circ (thinks \circ_{isl} \Diamond_l(\Diamond_r(distr \circ t) \circ smiled)))) \Rightarrow s & /_f L \\ \hline
(John \circ (X \bullet_f (thinks \circ_{isl} \Diamond_l(\Diamond_r(distr \circ t) \circ smiled)))) \Rightarrow s & P2 \\ \hline
(John \circ (thinks \circ_{isl} (X \bullet_f \Diamond_l(\Diamond_r(distr \circ t) \circ smiled)))) \Rightarrow s & Isl \\ \hline
(John \circ (thinks \circ_{isl} ((X \bullet_f \Diamond_r(distr \circ t)) \circ smiled))) \Rightarrow s & P1 \\ \hline
(John \circ (thinks \circ_{isl} ((distr \circ (X \bullet_f t)) \circ smiled))) \Rightarrow s & P2 \\ \hline
(John \circ (thinks \circ_{isl} ((distr \circ \Diamond X) \circ smiled))) \Rightarrow s & P0 \\ \hline
(John \circ (thinks \circ_{isl} ((distr \circ q(GQ, s, s)) \circ smiled))) \Rightarrow s & Lex \\ \hline
(John \circ (thinks \circ_{isl} ((distr \circ (shift \circ (three \circ men))) \circ smiled))) \Rightarrow s & Lex, /L, /L
\end{array}$$

Where $X = (s/_f(\Box GQ \backslash_f s))$.
Note that the scope of X is the whole sentence.

---

[4]As a shorthand for the multimodal decomposition of Qisl(A,B,C), we could extend the sequent rule for q(A,B,C) in (6) by constraining the bindingdomain Δ:

- There is no X such that $\Delta[X]$ and X isl-commands $Qisl(A, B, C)$, where:
- A M-commands B iff $(A \circ_M B)$ or $(A \circ_M C)$ and C dominates B.
- A dominates B iff A directly-dominates B or A directly-dominates C and C dominates B.
- A directly-dominates B iff $A = (B \circ_M C)$ or $A = (C \circ_M B)$ for arbitrary mode M.

c.

$$\dfrac{\dfrac{\text{(18d)} \qquad s \Rightarrow s}{Y \bullet_r \Diamond_l(t \circ smiled) \Rightarrow s}\,/_r L \qquad John \circ (thinks \circ_{isl}\, s) \Rightarrow s}{John \circ (thinks \circ_{isl} (Y \bullet_r \Diamond_l(t \circ smiled))) \Rightarrow s}\,/_{isl} L$$

$$\dfrac{John \circ (thinks \circ_{isl} (Y \bullet_r \Diamond_l(t \circ smiled))) \Rightarrow s}{John \circ (thinks \circ_{isl} ((Y \bullet_r t) \circ smiled)) \Rightarrow s}\,P1$$

$$\dfrac{}{John \circ (thinks \circ_{isl} (\Diamond Y \circ smiled)) \Rightarrow s}\,P0$$

$$\dfrac{}{John \circ (thinks \circ_{isl} (Qisl(np, s, s) \circ smiled)) \Rightarrow s}\,Lex$$

$$\dfrac{\dfrac{}{John \circ (thinks \circ_{isl} (GQ \circ smiled)) \Rightarrow s}\,Lex \qquad GQ \Rightarrow GQ}{John \circ (thinks \circ_{isl} ((GQ/GQ \circ GQ) \circ smiled)) \Rightarrow s}\,/L$$

Where Y is $(s/_r(\Box np \backslash_r s))$.

d.

$$\dfrac{\dfrac{\dfrac{\dfrac{np \circ smiled \Rightarrow s}{\Diamond\Box np \circ smiled \Rightarrow s}\,\Box L}{(\Box np \bullet_r t) \circ smiled \Rightarrow s}\,P0'}{\Box np \bullet_r \Diamond_l(t \circ smiled) \Rightarrow s}\,P1'}{\Diamond_l(t \circ smiled) \Rightarrow \Box np \backslash_r s}\,\backslash_r R$$

6 Conclusion

Although a choice-function account is feasible under a multimodal regime, it seems that the idea of in-situ interpretation is problematic in that a) a clear separation between closure and descriptive content cannot be given an appropriate formal treatment and b) a ban on movement beyond islands is incorrect. We showed that once we give up in-situ interpretation, the scope of indefinites can be accounted for in a uniform way; the q(A,B,C)-connective accounts for the scope of both GQ's and indefinites. By adopting a definition of *shift* $= q(GQ, s, s)/N$ we explain the island-escaping behavior of indefinites, intermediate scope and double scope as well. On the basis of this we argued that choice functions are not necessary in the process of interpretation.

References

Farkas, D. (1981). Quantifier scope and syntactic islands. *Proceedings of the seventieth Chicago Linguistics Society*, 59–66.

Fodor, J. and I. Sag (1982). Referential and quantificational indefinites. *Linguistics and Philosophy 5*, 355–398.

Kratzer, A. (1995). Scope or pseudoscope? Are there wide scope indefinites? In F.Hamm and A. von Stechow (Eds.), *Proceeding of Recent Developments in the Theory of Natural Language.* University of Tübingen.

Moortgat, M. (1996). In situ binding: a modal analysis. In Dekker and Stokhof (Eds.), *Proceedings Tenth Amsterdam Colloquium*, pp. 539–549.

Reinhart, T. (1996). Quantifier scope - how labor is divided between QR and choice functions. To appear in: Linguistics and Philosophy.

Reniers, F. (1997). How to (S)cope with Indefinites. Master's thesis, Utrecht. Http-link: wwwots.let.ruu.nl/users/Fabien.Reniers/mt.ps

Ruys, E. (1992). *The Scope of Indefinites.* Utrecht University: OTS dissertation series.

van der Sandt, R. (1992). Presupposition projection as anaphora resolution. *Journal of semantics 9*, 333–377.

Winter, Y. (1996). Choice functions and the scopal semantics of indefinites. To appear in: Linguistics and Philosophy.

A problem for choice functions: local presupposition contexts.

Maribel Romero
University of Massachusetts at Amherst

Choice functions have been argued to yield the right truth conditions for interpreting island-embedded *which* phrases and indefinites in situ. This paper presents examples of local presupposition projection that challenge the current choice function approach, since these local presuppositional readings cannot be derived without also weakening the general truth conditions.

1. Background.

This paper is concerned with the LF- and semantic representation of in situ *which* phrases and indefinite Noun Phrases (NPs) like the ones in (1) through (4). The problem that these phrases present is how to derive their wide scope reading outside the island.

(1) Q: Who read every book that which philosopher wrote?
A: # Mary read every book that Bill Clinton wrote.
(2) Mary read every book that a certain philosopher wrote.
(3) Q: Who did not consider the possibility that which politician is corrupt?
A: # Max didn't consider the possilitity that James Dean is corrupt.
(4) Max didn't consider the possilitity that some politician is corrupt.

A first possibility is to propose that these phrases move outside the island at LF, assuming that LF *wh*-movement and QR of indefinites are island-insensitive. However, Ruys (1992, 1995) showed that the wide scope of these phrases is not gained through such movements, since such movements would wrongly allow for a distributive interpretation that island-escaping *wh*-phrases and indefinites do not have:

(5) If three relatives of mine die, I will inherit a house.[1]

a. √ Collective reading: "There are three relatives of mine such that, if each of them dies, I will inherit a house."

λw. $\exists X_e$ [three(X) & relatives-of-mine(X) & $\forall$w' accessible to w

[(Dλz.z dies in w')(X) $\rightarrow$ I inherit a house in w']]

b. * Distributive reading: "There are three relatives of mine for each of whom it is true that, if (s)he dies, I inherit a house."

λw. $\exists$X [three(X) & relatives-of-mine(X) & (Dλz.$\forall$w' accessible to w

[z dies in w'$\rightarrow$ I inherit a house in w']) (X)]

A second alternative is to interpret these phrases in situ and assume that the individual variable that they introduce is unselectively bound by a question operator or $\exists$-closure higher up in the tree. This would avoid the problems that the movement approach presents, but unfortunately it yields too weak truth conditions. As Reinhart points out, any non philosopher in the actual world w, --e.g. Bill Clinton-- satisfies the implication in (6) and, thus, his mere existence makes the sentence true in w. Similarly, any non politician in the actual world w about whom John did not consider the possibility that

---

[1] *D* in (5) is the distributive operator.

(s)he is a politician in the actual world w --e.g. James Dean--, makes (7) true in w. The same reasoning can be applied to the questions in (1) and (3): the answers *Bill Clinton* and *James Dean* are wrongly predicted to be felicituos true answers for (1Q) and (3Q) respectively.

(6) a. Mary read every book that a certain philosopher wrote.

b. $\lambda w.\exists x \forall y$ [(y is a book that x wrote in w and x is a philosopher in w) $\rightarrow$ Mary read x]

(7) a. Max didn't consider the possilitity that some politician is corrupt.

b. $\lambda w.\exists x \neg$(Max considered the possibility in w that ($\lambda w'$. x is a politician in w & x is corrupt in w'))

We might be able to avoid the problem in (1) and (6) by invoking a semantic/pragmatic ban against empty restrictors (Strawson 1952), which is independently needed to predict the oddity of dialog (8). However, Cresti (1995) shows that this solution does not extend to cover (3) and (7), since in these cases the empty set (of possible worlds) is not in the restrictor of an operator. As (9) shows, the impossible proposition (the empty set of possible worlds) can perfectly be the argument of an attitude.

(8) Q: Who read every book that which philosopher wrote?

A: # Mary read every book that Socrates wrote.

(9) Shawn may be bad at math, but he didn't assume that 2 plus 2 equals 5.

In conclusion, neither the LF-movement analysis nor the standard unselective binding approach capture correctly the truth conditions of in situ *which* phrases and wide scope indefinites.

2. The choice function approach.

A third strategy is the choice function approach. This approach pursues the in situ line --thus avoiding the problems that the movement analysis has to face--, except that the *which* phrases and indefinite NPs at issue introduce not an individual variable but a choice function variable to be bound higher up. Choice functions have different semantic types for different authors (see Engdahl 1980; Kratzer 1995; Reinhart 1992, 1995, 1997; Winter 1997), but all the different implementations roughly share the following core idea:

(10) A function f is a choice function (CH(f)) if, for every set P in its domain, f(P) is a member of P.

Reinhart and Winter show that the problem of too weak truth conditions disappears for the examples (1)-(4) if we use choice functions. The examples (1)-(4) are now assigned the denotations (11)-(14). In (11) and (12), for instance, the in situ phrases *which philosopher* and *a certain philosopher* denote, for a given f, the individual f(philosopher), which, according to the description of choice function in (10), can only be an individual selected out of the set of (actual) philosophers, hence, an (actual) philosopher.[2]

(11) a. Who read every book that which philosopher wrote?

---

[2] Reinhart guarantees that the chosen philosopher is an actual philosopher (and not a philosopher at some other world) by giving choice functions the type <<s,et>,e> and requiring that $f(P) \in {}^{\vee}P$ for each P in the domain of f (except for the empty set).

b. {p: ∃g,f [CH(g) & CH(f) & true(p) & p = λw. ∀x [f(philosopher) wrote x in w → g(person) read x in w]]}

(12) a. Mary read every book that a certain philosopher wrote.

b. λw.∃f [CH(f) & ∀x [f(philosopher) wrote x in w → Mary read x in w]]

(13) a. Who did not consider the possibility that which politician is corrupt?

b. { p: ∃g,f [CH(g) & CH(f) & true(p) & p = λw. ¬ (g(person) considered the possibility in w that (λw'. f(politician) is corrupt in w'))]}

(14) a. Max did not consider the possibility that some politician is corrupt.

b. λw.∃f [CH(f) & ¬[Max considered the possibility in w that (λw'. f(politician) is corrupt in w']]

What happens, though, when the N(oun)-restrictor in the *wh*- or indefinite phrase denotes the empty set, as in (15)? How could a choice function possibly select an individual out of the empty set?

(15) a. Max checked every law that a certain American king had sanctioned.

b. λw.∃f [CH(f) & ∀x [(x is a law in w & f(American king) sanctioned x in w) → Max checked x in w]]

Two main strategies to handle empty N-restrictors are possible.

The first one is to consider that choice functions are partial functions and that the empty set is not in their domain. Then, in a world w where the set of American kings is empty, f(American king) is undefined for any f, which will make the implication in (15b) undefined for some values of x, and, as a result, will make the whole proposition (15b) undefined too.[3] That is, (15a) presupposes the existence of a non-empty set of American kings

The second possibility is to consider that a choice function is a total function and that it yields a falsifying object when the N-restrictor is empty, as in von Stechow (1996), Reinhart (1997) or Winter (1997). Let us take, for the sake of illustration, Winter's definition of a choice function:

[3] In Kleene's three-valued logic, the truth value of an implication with an undefined antecedent is true if the consequent is true and undefined otherwise. This means that, unless Max checked absolutely all the laws in w, there will be some values of x for which the implication within (15b) will be undefined. Assuming that ∀ amounts to multiple conjunction and ∃ amounts to multiple disjunction and assuming Kleene's three-valued system of connectives, we have that the universally quantified formula within (15b) is undefined for a world w with no American kings and so it is the whole proposition (15b).

(16) A function $f \in D_{<<et><et,t>>}$ is a choice function iff:

(i) for all $P \in D_{<et>}$ such that $P \neq \emptyset$, $\exists x_e[P(x) \ \& \ f(P)=\lambda A_{<et>}.A(x)]$ (i.e., f(P) is the generalized quantifier corresponding to some individual in P), and

(ii) $f(\emptyset)=\emptyset_{<et,t>}$ (the trivial generalized quantifier which does not include any set of individuals).

Assuming that there are no American kings in w, the definition (16) makes the antecedent of the conditional in (15b) false for any pair of f and x. Hence, the whole existential quantification is trivially true in w. That is, (15) is true in a world w where there is no American king.

Judgments about the truth conditions of (15) are subtle and it is not the aim of this paper to discuss which of the two alternatives is empirically more accurate. In the next section, we present some local presupposition examples and show that neither the partial choice function strategy nor an extension of the falsifying object strategy can account for them, hence posing a problem for the current choice function approach to *which* phrases and indefinites.

3. Local presupposition projection in the choice function approach.

The following examples involve local projection of the existence presuppositions triggered by the definite NPs *his dog* and *his younger sister*, namely the presuppositions "that there is a (unique) x that is his dog" and "that there is a (unique) x that is his younger sister". E.g., under its most normal reading, the sentence in (17) does not have the global presupposition that everybody owns a dog, but the existence presupposition locally projects within the restrictor of *every*. Similarly, in (18), the presupposition does not project globally but locally, within its nuclear scope of *every*.

(17) a. Lucie got mad at everybody$_1$ who mistreated his$_1$/her$_1$ dog (i.e., at everybody who owns a dog and mistreated it).

b. $\lambda w.\forall x$ [$\exists y$[y is x's dog in w & x mistreated y in w] $\rightarrow$ Lucie got mad at x in w]

(18) a. Mary didn't assume that every boy$_1$ in the class would bring his$_1$ younger sister --since she knows that not every boy in the class has a younger sister.

b. $\lambda w.\neg$[Mary assumed in w ($\lambda w'.\forall x$ [boy(x)(w') $\rightarrow \exists y$ [y is x's younger sister in w' & x brought y in w']])]

Parallel examples of local presupposition projection occur with *which* phrases (examples (19)-(20)) and with indefinites (examples (21)-(22)), too:

(19)Q: Who got mad at everybody$_1$ who mistreated which pet of his$_1$?

A: Lucie got mad at everybody who mistreated his/her dog (i.e., at everybody who owns a pet-dog and mistreated it).

(20) Q: Who didn't assume that every boy$_1$ in the class would bring which relative of his$_1$ --since that person knew that not every boy in the class has such a relative?

A: √ Mary didn't assume that every boy$_1$ in the class would bring his$_1$younger sister --since Mary knows that not every boy in the class has a younger sister.

(21) Lucie got mad at $everybody_1$ who mistreated a certain pet of his_1.
(22) Mary didn't assume that every boy_1 in the class would bring a certain relative of his_1.

These examples present a problem for the current choice function approach to *which* phrases and indefinites: we need to allow for these local presupposition readings, but neither the partial function approach nor an extension of the falsifying object approach can derive (19)-(22) without yielding too weak truth conditions.

Let us first look at the partial choice function line. The local presupposition reading of (21) could be represented as in (23b):

(23)a. Lucie got mad at $everybody_1$ who mistreated a certain pet of his_1.

b. $\lambda w.\ \exists f\ CH(f)\ \&\ \forall x\ [\ (\ f(\text{pet of } x) \text{ is defined } \&\ x \text{ mistreated } f(\text{pet of } x) \text{ in } w\ )\ \rightarrow \text{Lucie got mad at } x \text{ in } w\ ]$

The problem with the formula in (23b) is that it has too weak truth conditions, a problem that we already encountered in the unselective binding approach. First, let us take a partial choice function that systematically chooses people's dogs when it can and that is undefined when the argument set does not contain any dog. The existence of this function suffices to make the proposition in (23b) true in a world w where dogs are pets and where Lucie got mad at people who own a dog and mistreated it. The existence of the function $f_{his\ dog}$, hence, derives a possible local presupposition reading of (23a). However, also a function that systematically chooses people's uncles and that is undefined otherwise would make the proposition (23b) true in a world w where uncles are not pets, everybody mistreated all their pets and Lucie didn't get mad at anybody at all. This is so is because there is an f in w --namely, $f_{his\ uncle}$-- such that, for any x, $f_{his\ uncle}$(pet of x) is undefined, the antecedent of the conditional is always false and the implication is vacuosly true. That is, the sentence (23a) would be true even if Lucie did not care at all about pets.

The same problem of too weak truth conditions arises when the *wh*-phrase or the indefinite is in the nuclear scope of an operator. The proposition in (24b) wrongly yields the value true for a world w where every boy has relatives, where Mary assumes that every boy would bring all his relatives, where cats are not relatives and where Mary does not assume the impossible proposition. This is so because we can always find a partial choice function -- e.g. $f_{his\ cat}$-- for which the formula ($\lambda w'$. ...) stands for the impossible proposition.

(24)a. Mary didn't assume that every boy_1 in the class would bring a certain relative of his_1.

b. $\lambda w.\ \exists f\ CH(f)\ \neg[\text{Mary assumed in } w\ (\lambda w'.\forall x\ [boy(x)(w') \rightarrow f(\text{relative of } x) \text{ is defined } \&\ x \text{ invites } f(\text{relative of } x) \text{ in } w'\ ])\ ]$

The same reasoning applies to the *which* phrase examples (19)-(20).

Let us now try to extend the falsifying object strategy to cover these cases. Take a choice function that systematically chooses people's dogs when it can and that yields the falsifying object when the argument set does not contain any dog. Under this value of *f*, the universally quantified formula within (23c) is true in a world w if, for every x, x did not have a pet-dog, or x had a pet-dog but did not mistreat it, or x had a pet-dog, x mistreated it and Lucie got mad at x. These are, indeed, the right truth conditions. However, we get parallel truth conditions for a function that systematically chooses people's uncles when it can and the falsifying individual otherwise. The mere existence of this function makes the proposition in (23c) true in a world w where nobody has pet-uncles, independently of Lucie having any concern about pet abuse. A similar case can be drawn for (24) and for the *which* phrase examples in (19)-(20).

(23) c. $\lambda w.\ \exists f\ \ CH(f)\ \&\ \forall x$ [x mistreated f(pet of x) in w $\rightarrow$ Lucie got mad at x in w]

Selected References

Beaver, D. *Presupposition and Assertion in Dynamic Semantics*. Ph.D. dissertation, University of Edinburgh.

Cresti. D. 1995. *Indefinite Topics*. PhD dissertation. Cambridge: MITWPL.

Kratzer, A. 1995. "Scope or Pseudoscope? Are there wide scope indefinites?". University of Massachusetts ms.

Reinhart, T. 1997. "Quantifier scope: How labor is divided between QR and choice functions, *L&P*.

Ruys, E.G. 192. *The scope of indefinites*. PhD dissertation, Utrecht University.

von Stechow, A. 1996. "Some remarks on choice functions and LF-movement". University of Tuebingen ms.

Strawson, P. F. 1952. *Introduction to Logical Theory*. London: Methuen.

Winter, Y. 1997. Choice functions and the scopal semantics of indefinites", *L&P*.

Descriptive pronouns in Dynamic Semantics*

Robert van Rooy
University of Amsterdam

In this paper I argue for the existence of descriptive pronouns, and that the constraints for descriptive pronouns involve a notion of uniqueness, *not* one of *accessibility*. I also shown how such pronouns can be accounted for in dynamic semantics, and that with it we can account for many phenomena problematic for the standard dynamic account.

According to Gerath Evans (1977), pronouns should either be treated as bound variables or as *E-type pronouns*. Pronouns inside the smallest clause containing a quantified expression are treated as bound variables of quantification theory, while other occurrences of pronouns, so-called *unbound pronouns*, are treated as E-type pronouns referring to *all* the relevant objects by which the antecedent sentence is verified. Evans argued that an E-type analysis is needed for at least some occurrences of pronouns in order to interpret a sentences like *Tom owned some sheep and Harry vaccinated* <u>*them*</u> as saying that Harry vaccinated *all* sheep that Tom owned. Following Neale (1990), we can treat E-type pronouns as *descriptive pronouns*, going proxy for the description recoverable from the antecedent sentence. Thus, in a sequence of the form *Some S are P. They are Q*, the pronoun *they* is going proxy for the description *(all) the S such that P*.[1]

However, if we use the term *unbound pronoun* in the above sense, it seems that not all unbound pronouns can be treated as going proxy for the definite or universal noun phrase recoverable from the antecedent clause, and thus should be treated as E-type pronouns. For example in *Yesterday, some men came at the door.* <u>*They*</u> *were strangers,* we don't want to say that *they* needs to stand for all men that came at the door yesterday. If we want to say that the pronoun is going proxy for a description recoverable from its antecedent, the relevant description should not be definite or universal, but *indefinite*, like <u>*Some*</u> *men that came at the door yesterday*.[2] Something similar should be done to get the right reading of a discourse like *A man is walking in the park.* <u>*He*</u> *is whistling*, because the second sentence can be true if only one of the two men walking in the park is whistling. But claiming that the pronoun is an abbreviation of an *indefinite* description would be very implausible. Pronouns are (interchangeable with) *definite* expressions.

This doesn't mean that all unbound pronouns should be treated as E-type pronouns after all. Although the uniqueness presupposition can sometimes be explained away by domain selection, this cannot always be done as shown by donkeys in bishop clothing's: *If a bishop meets another man, he blesses him.*[3] If E-type pronouns are treated as *definite* descriptions, it seems to be impossible to select the domain in the correct way.

But if all occurrences of singular pronouns cannot be treated as definite descriptions that (in extensional contexts) refers to (all) *the* objects that verify their antecedent clauses, how then can a pronoun be treated as a definite expression?

The answer of proponents of DRT/FCS/DPL is familiar by now: treat anaphoric pronouns simply as bound variables, interpret indefinites dynamically such that they introduce new objects available for reference, and assure that in case of negation a universal quantification over assignment functions or sequences of individuals is involved. Anaphoric pronouns can be treated as definite noun phrases, because the possibilities with respect to which the pronouns are interpreted are made more fine-grained entities then possible worlds, namely, world-assignment pairs.[4]

---

* Thanks to Paul Dekker, Hans Kamp, and Ede Zimmermann for discussion.

1 This in distinction with Evans (1977) who argued that E-type pronouns *rigidly refer*.

2 See Sommers (1982).

3 Due to Heim (1990), and attributed to Kamp and Van Eijck.

4 Actually, I believe that most anpahorically used pronouns can be treated as definite noun phrases because they are *referentially* used, referring to the unique *speaker's referent* of its antecedent indefinite. In Van Rooy (1997a) it is shown that by means of *diagonalisation* and the use of *hypothetical* reference contexts such an analysis can be pushed much further than many have supposed, and that in fact this analysis is close to, although not identitical with, standard DRT/FCS/DPL. Also, it is this referential

Although original DRT/FCS/DPL is quite successful in accounting for anaphoric dependencies across sentential boundaries, the theory is not without its problems. The main *empirical* problem is that the predicted constraints on anaphoric binding are sometimes too rigid. In the following, I will discuss a recent paper of Krahmer and Muskens (1995) where it is proposed to solve these empirical problems simply by relaxing these constraints. I will argue, however, that their proposal leaves something unexplained, and that this can be accounted for naturally by the E-type approach. Later, I will account for the existence of descriptive pronouns in dynamic semantics.

Consider the following sentences:

(1) Either John does not own a donkey or he keeps *it* very quiet. (Evans, 1977)
(2) It is not true that John didn't bring an umbrella.
It was purple and *it* stood in the hallway. (Krahmer and Muskens, 1995)

It is well known that the standard dynamic account has problems with such sentences. The reason is that in it negation is treated as a plug with respect to anaphoric binding. Note that contrary to the standard dynamic approach, negations don't have this property according to the E-type account. Proponents of the standard dynamic account argue that negations *should* be treated as plugs, how else to account for the unacceptability of (3)?

(3) *There is no guest at this wedding. *He* is standing right behind you.

The unacceptability of (3) can be accounted for by *syntactic* means. An object 'introduced' under the scope of a negation cannot be picked up by anaphoric means in further discourse. But the E-type approach has, of course, no problem with the unacceptability of (3). The sequence (3) is out, not for syntactic but for *semantic* reasons. The context resulting after the interpretation of the first sentence of (3) contains no world in which there is a guest at this wedding. If the pronoun *he* of the second sentence would stand for *the guest at this wedding*, the second sentence could not be true. That's the reason why (3) is out. That is quite a natural reasoning, I would say. And does the acceptability of the sentences (1) and (2) not justify this reasoning?

Not so, say Krahmer & Muskens (1995). Negation is a syntactic plug with respect to anaphoric binding, and the reason why (1) and (2) are acceptable is that a double negation is a plug unplugged. A clause of the form ~~A is not only truth-conditionally, but also *dynamically* equivalent with A. They can account for this claimed equivalence by using techniques from partial logic.[5]

There are some worries with their approach, however. First, intuitively there seems to be no difference between (1) and a sentence like *It is possible that John does not own a donkey, but it is also possible that he keeps it very quiet.* It would be nice if both could be handled by the same mechanism, but it is rather doubtful that this mechanism will be that ~~A is equivalent to A. Second, if a pronoun refers back to an indefinite used under the scope of two negations, it seems that the pronoun can never take the indefinite as its syntactic antecedent if it is presupposed that there are more objects in one of the worlds that the indefinite could have referred to. It seems that Krahmer & Muskens (1995) agree. Discussing the contrast in acceptability between (4a) and (4b),

(4a) It is not true that there is *no guest* at this wedding.
*?*He* is standing right behind you.
(4b) It is not true that there is *no bride* at this wedding.
She is standing right behind you.

they say that the distinction is due to a uniqueness effect.

---

analysis of pronouns, rather than standard DPL, that is truly non-representational and which suggests that pronouns can also be used descriptively.

[5] A similar effect is reached by Dekker (1993, chapter 2), though in a rather different way.

Given some highly unlikely context in which it is understood between speaker and hearer that at most one guest can be present at this particular wedding [4a] would be fine. We feel that it is precisely the unlikelyhood of such a context which explains the markedness of [4a]. (Krahmer & Muskens, p 359)

I completely agree. But then they make the following claim about these problematic cases:

Since such apparent counterexamples on closer examination turn out to be no counterexamples at all, it seems we can take it as a general rule that as far as truth conditions and the possibility of anaphora are concerned double negations in standard English behave as if no negation at all were present. (Krahmer & Muskens, 1995, p. 359)

I'm afraid that I don't understand this. That you can explain why a counterexample to your approach *is* a counterexample, doesn't mean that on closer examination it 'turns out to be no counterexample at all'.[6]

I want to propose to take the counterexample seriously. The speaker can appropriately use a singular pronoun that takes an indefinite as its syntactic antecedent although original DRT/FCS/DPL predicts that the antecedent is not accessible only in case it is presupposed, understood between speaker and hearer, that there is exactly one object that the indefinite can refer to.[7]

This is also what's going on, I think, in Peirce's puzzle as discussed by Gillon (1996). In the standard dynamic approach, as in ordinary predicate logic, (a) $\exists xA \vee \exists yB$ is logically equivalent with (b) $\exists x[A \vee B]$. However, it seems that we have to translate a sentence like *Either someone would win $1.000, if everyone took part, or someone will not take part* by $\exists x[A > Cx] \vee \exists yB$ and *Either someone will win $1.000, if everyone would take part, or he will not take part* in standard dynamic semantics by $\exists x[(A > Cx) \vee B]$ (to account for co-reference) that are not equivalent to each other. To see this, consider the following situation: There is a sweepstakes in which only one thousand people are eligible to participate. Tickets are sold for $1 each. No participant is permitted to buy more than one ticket. And the winner will take the total of the stakes, if everybody takes part. In this situation, the first sentence is true, but the second false. This example does not falsify the equivalence between $\exists xA \vee \exists yB$ and $\exists x[A \vee B]$ in ordinary predicate logic, of course. It only shows that we should not represent the second sentence, *Either someone will win $1.000, if everyone would take part, or he will not take part*, by a formula like $\exists x[(A > Cx) \vee B]$, but by $\exists x[A > Cx] \vee B$, instead, and treat the pronoun as a *descriptive* pronoun going proxy for the antecedent sentence. As Gillon observes, in this way we can account for the fact that the two sentences have a different meaning. The one who would win $1.000 should everyone take part, might still take part and win, but less than $1.000, because someone else does not take part.

I conclude that to account for E-type pronouns in dynamic semantics, we have to implement the following ideas. First, you can always refer back with a singular pronoun to an indefinite if in each world of the relevant context there is only one object that could be a referent of the indefinite that verifies the antecedent sentence. For that reason, second, negations should not be treated as absolute syntactic plugs with respect to anaphoric binding.[8]

---

6 It is sometimes assumed that we can account for bathroom sentences by representing sentences of the form "Not P or Q" by something like "$\sim P \vee (P \wedge Q)$". But this does not only give rise to the same problem as the approach of Krahmer & Muskens, it is also purely ad hoc.

7 For extra motivation, consider the following contrast observed by Partee (1972) between *John was looking for the man who murdered Smith, and Bill was looking for him too*, and *John was looking for a gold watch, and Bill was looking for it too*. The pronoun *him* in the former sentence can be used when the speaker has no particular man in mind, but the pronoun *it* in the latter sentence cannot be used when the speaker has no particular watch in mind. The reason is, according to Partee, that in the latter case it cannot be presupposed that there is exactly one golden watch.

8 I same should be done for other constructions (like "possibly") that normally are treated as plugs with respect to anaphoric binding. See Van Rooy (1997a) for more on this.

To implement descriptive pronouns into dynamic semantics I extend Dekker's (1993) formalisation of dynamic semantics and use two assignment functions, instead of just one. The first one represents properties introduced by indefinites, while the second one assigns individuals (rigid concepts) to variables. Only properties can 'escape' syntactic islands.

Formalisation[9]

The *syntax* of the language L will not be specified explicitly, but is given implicitly in the semantic clauses. *Models* are triples $\langle D, W, I \rangle$, where D is a non-empty set of objects, W a non-empty set of possible worlds, and I the intensional interpretation function that maps *n*-ary relations to a function from worlds to sets of *n*-tuples of objects. The set of *partial assignments* associated with D and L, G, is $\cup\{[W \rightarrow \wp(D)]^X \mid X \subseteq VAR_L\}$. Hence, technically, variables are always assigned properties - but some of these properties represent ordinary objects: the set **D** of *rigid concepts* is $\{\mathbf{d} \mid d \in D\}$, where $\mathbf{d} = W \times \{d\}$. *Possibilities* are triples, elements of $G \times G \times W$, and *information states* are sets of possibilities. I will use the following notational conventions with assignments *g*, *h* and *h'*, objects *d* and *o* , variables *x* and *y*, worlds *w*, and information states S, where $x \notin dom(g) \cup dom(h)$ and for no $\langle g,h,w \rangle \in S$: $x \in dom(g) \cup dom(h)$:

$$g[x/o] = \{\langle y,g(y)\rangle \mid y \in dom(g) - \{x\}\} \cup \{\langle x,o\rangle\}$$
$$S[x/d] = \{\langle g,h',w\rangle \mid \exists h: \langle g,h,w\rangle \in S \;\&\; h' = h[x/\mathbf{d}]\}$$
$$W(S) = \{w \in W \mid \exists g,h: \langle g,h,w\rangle \in S\}$$

The elements of $(G \times G \times W)$ are ordered by $\leq$: $\langle g,h,w\rangle \leq \langle g',h',w'\rangle$ iff $w = w'$, $g \subseteq g'$, and $h \subseteq h'$. This ordering relation carries over to information states S and S': $S \leq S'$ iff for every $\alpha \in S$: there is an $\alpha' \in S'$: $\alpha \leq \alpha'$. For the recursive definition of the context change potential [[A]] $[\subseteq \wp(G \times G \times W) \times \wp(G \times G \times W)]$ of formulae A of L, only the interpretation rules for "$\exists$xA", singular terms, and "~A" are surprising and will be discussed in some detail. First, like discussed above, formulae of the form "$\exists$xA" will not only introduce a specific individual, but also the (assignment dependent) property *being an A*:[10]

$$[[\exists xA]](S) = \{\langle g'[x/\hat{x}|A|^g_h],h',w\rangle \mid \langle g,h,w\rangle \in S \;\&\; g \subseteq g' \;\&\; h \subseteq h' \;\&\; \langle g',h',w\rangle \in \cup_{d \in D}[[A]](S[x/d])\},^{11}$$
if $\forall g \in \{g \in G \mid \exists h,w: \langle g,h,w\rangle \in S$ or $\langle h,g,w\rangle \in S\}: x \notin dom(g)$, undefined otherwise

The abstraction $\hat{x}|A|^g_h$ used in the interpretation rule for indefinites is that function $f : W \rightarrow \wp(D)$ such that for any $w \in W$: $f(w) = \{d \in D \mid [[A]](\{\langle g,h[x/\mathbf{d}],w\rangle\}) \neq \emptyset\}$.

Second, to account for the uniqueness presupposition, variables that represent singular pronouns are interpreted as follows:

$$||x||^{g,h,w} = \$(h(x)(w)), \text{ if } x \in dom(h), \text{ else}$$
$$\$(g(x)(w)), \text{ if } x \in dom(g) \text{ and } \$(g(x)(w)) \text{ is defined, undefined otherwise}$$

---

[9] See Van Rooy (1997a) for more details, and for an extension of the account to *paycheck pronouns*.
[10] Quantified expressions will only introduce properties. For implementation, see Van Rooy (1997b).
[11] Note that it follows that the variable *x* is in the domain of both the first and the second assignment function of a possibility. This is the reason for the somewhat involved interpretation rule for terms.

where $\$(\{u\}) = u$ and $\$(T)$ is undefined, if T is not a singleton set.[12]

Third, if we want to account for descriptive pronouns in dynamic semantics in a systematic way we have to change also the interpretation rule of negation. What has to be accounted for is that (i) indefinites under the scope of a negation will not introduce specific individuals, (ii) that properties can be introduced by such indefinites, but (iii) that indefinites under the scope of a negation do not introduce properties on the main level that are *dependent* on other terms that stand in monotone decreasing position whose referent is not yet established. For instance, I don't want to introduce properties corresponding with *a woman* in *if a man buys a flower, he gives it to a woman*, because the property introduced by this indefinite in the consequent depends on the referents of *a man* and *a flower* that stand in the antecedent of the conditional. In the interpretation rule below, the first condition is the usual one for negation in dynamic semantics and takes care of (i). The second condition takes care of (ii) and (iii). It says that the properties introduced by ~A are those properties introduced by subformulae ∃xB of A that introduce only a single property to the main context. In the following interpretation rule I assume that underlined variables are bound.

$$[\![\sim A]\!](S) = \{\langle g',h,w\rangle \mid \exists g: \langle g,h,w\rangle \in S \ \&\ \sim\exists h'' \supseteq h: \exists g'' \supseteq g: \langle g'',h'',w\rangle \in [\![A]\!](S) \ \&\ g' = g \cup \{\langle y,o\rangle \mid \exists k,h',w': \langle k,h',w'\rangle \in [\![A]\!](\{\langle \underline{g},\underline{h},w''\rangle \mid w'' \in W\}) \ \&\ y \in dom(k)\backslash dom(g) \ \&\ \forall l,m,n,n': \langle l,n,w'\rangle, \langle m,n',w'\rangle \in [\![A]\!](\{\langle \underline{g},\underline{h},w''\rangle \mid w'' \in W\}): l(y) = m(y) = o\}\}$$ [13]

The notions of acceptability and entailment are defined as usual: A formula A is *acceptable in S*, S⊨A, iff S ≤ [[A]] (S), and B follows from A, A⊨B, iff for all S: [[A]] (S) is a substate of [[B]] ([[A]] (S)).

Let's now discuss a sentence like (1), represented as "~∃xPx ∨ Qx":

$$[\![\sim\exists xPx \vee Qx]\!](S) = \{\langle g[^{x}/I(P)],h,w\rangle \mid \langle g,h,w\rangle \in S \ \&\ \sim\exists g',h': g' \supseteq g \ \&\ h' \supseteq h: \langle g',h',w\rangle \in [\![\sim\sim\exists xPx \wedge \sim Qx]\!](S)\}$$

If we assume that in every world in W(S) there was at most one P, the singular pronoun represented as *x* in Qx can be interpreted, because the formula "~~∃xPx" not only eliminate worlds in which there is no P, it also introduces the property *being a P*. Note that if <g,h,w> is an element of [[~∃xPx ∨ Qx]] (S), the variable *x* will also be in the domain of g, and g(x) will denote in every world all the P's in the world. This is not problematic, because of the definedness conditions on terms (and atomic formulae). My theory predicts that you can only use a singular E-type pronoun that is interpreted as *the P*, if in all worlds in W(S) there exists exactly one P. But given that we have used a disjunction, and thus that in S it is an issue whether there exist a P, this will typically not be the case.

Once we assume that singular pronouns can always pick up antecedents introduced in positions predicted to be inaccessible by the standard account if the uniqueness condition is met, we can also explain in a systematic and compositional way the fact that *proper names* can almost always be anaphorically picked up by singular pronouns irrespective of

[12] For plural pronouns this definedness condition does not apply, and they thus automatically receive the *exhaustive* interpretation. For a use of this exhaustivity effect for the analysis of questions, see Van Rooy (1997b).

[13] As usual, disjunction and implication are treated syncategorematically, by having "(A ∨ B)" and "(A → B)" stand for "~(~A ∧ ~B)" and "~(A ∧ ~B)" respectively.

the position in which the name was used. We don't need a special proper name rule to account for this if we assume that proper names should be treated as rigid designators.

Something similar is true for *definite description*. If we assume that a sentence like *The N is P*, where *the N* is used non-anaphorically, is represented as "$\iota x[Nx] \wedge Px$", and that in general "ιxA" is short for "$\exists x \forall y[A[^x/_y] \leftrightarrow y = x] \wedge A$", where $A[^x/_y]$ is A with all occurrences of free x replaced by fresh y, we can explain why the pronoun in the second sentence of the following example of Van der Sandt (1992) is used appropriately:

(5) If John makes coffee, *his wife* will be happy. *She* is such a nice person.

Not the conditional gives rise to the presupposition that John has a wife, as suggested by Van der Sandt, but the sentence in which the descriptive pronoun occurs. Note that if in the antecedent of (5) we substituted *John* by the indefinite *a woman*, the description *his wife* could not be anaphorically picked up by a subsequent sentence, which is indeed what I predict.

Note that by our interpretation rules it is predicted to be possible that sometimes a pronoun can pick up a description that is interpreted in a world, or a more complex index, that is not an element of the set of indices of the context resulting after the interpretation of the indefinite. This is good news. Examples are easy to find where non-rigid concepts seem to be useful:

(6) Senator Green believed that he had nominated *the winner of the election*, but Senator White believed that she had nominated *him*. (Partee, 1972)[14]

(7) Last year *my home* was in Stuttgart. Now *it*'s in Amsterdam. (after Evans, 1977)

Literature

Dekker, P. (1993), *Transsentential Meditations*, Ph.D. dissertation, Amsterdam.

Evans, G. (1977), "Pronouns, quantifiers and relative clauses (1)", *The Canadian Journal of Philosophy*, 7, 467-536.

Gillon, B. (1996), "Three theories of anaphora and a puzzle from C.S. Peirce". In: P. Dekker and M. Stokhof (eds.), *The Proceedings of the 10'th Amsterdam Colloquium*, ILLC, University of Amsterdam.

Groenendijk, J. and M. Stokhof (1991), "Dynamic predicate logic", *Linguistics and Philosophy*, 14, 39 - 100.

Heim, I, (1990), "E-type pronouns and donkey anaphora", *Linguistics and Philosophy*, 13, 137-178.

Krahmer E. and R. Muskens (1995), "Negation and disjunction in discourse representation theory", *Journal of Semantics*, 12, 357 - 376.

Neale, S. (1990), *Descriptions*, MIT Press, Cambridge.

Partee, B. (1972), "Opacity, coreference, and pronouns", In: D. Davidson and G. Harman (eds.) *Semantics of Natural Language*, Reidel, Dordrecht, 413- 441.

Rooy, van R. (1997a), *Attitudes and Changing Contexts*, Ph.D. dissertation, Stuttgart.

Rooy, van R. (1997b), "The context-dependence of questions and answers", these proceedings.

Sandt, van der R. (1992), "Presupposition projection as anaphora resolution", *Journal of Semantics*, 9, 223-267.

Sommers, F. (1982), *The Logic of Natural Language*, Oxford: Clarendon Press.

[14] Partee (1972) notes that (21) is ambiguous. Either the two senators dispute over who nominated a certain person, or over who the winner of the next election will be, the one nominated by Green or the one nominated by White. She concludes that therefore a sentence like (6) "constitutes a real problem for any attempt to find a uniform basis for the pronoun-antecedent relationship" (p. 425).

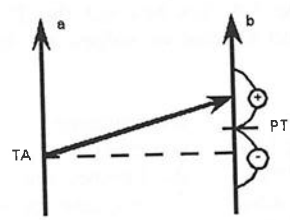
Aspectual duality regained

Hans Smessaert
F.W.O.-Vlaanderen & K.U.Leuven

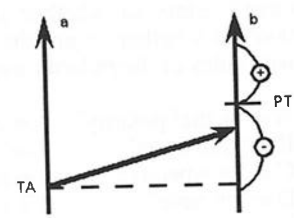
The view that the four aspectual adverbials <*not yet (nog niet), already (al), still (nog), no longer (niet meer)*> constitute a duality square which runs parallel to the <¬∃ , ∃ , ¬∀ , ∀ > square of Predicate Logic (Löbner, 1990; Vandeweghe,1992) has been criticised recently (Van der Auwera, 1993; Mittwoch,1993; De Mey,1994). Although this paper basically agrees with those criticisms, it argues that a much richer notion of duality emerges in the case of Dutch when *al* is taken out of the initial paradigm and related to other adverbials expressing focus meaning. On this view, *al* has three different duals, two lexical ones, namely *eindelijk (finally)* and *nog altijd (STILL)*, and one compositional, namely *al bijna niet meer (already almost no longer)*. Eight focus adverbials are analysed along five dimensions of polarity, and the different kinds of internal, external and dual negation are modelled in terms of switching operations on various polarity dimensions.

Aspectual focus adverbials can be represented graphically as in (1). The a-scale represents clock-time (the time adverbial TA indicating reference time), whereas the b-scale represents the event time containing a polarity transition PT from a negative to a positive state (i.e. the beginning):

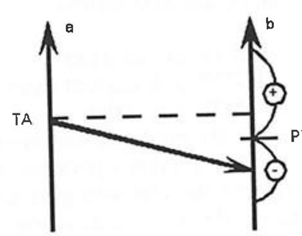
(1)



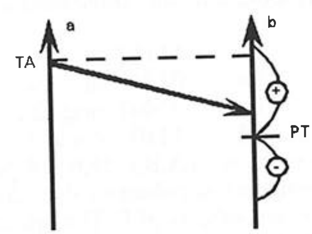
a. Jan sliep toen *al*.
(John was *already* asleep then)



b. Jan sliep toen *al bijna*.
(John was *already almost* asleep then)



c. Jan sliep toen *nog altijd niet*
(John was *still not* asleep then)



d. Jan sliep toen *eindelijk*
(John was *finally* asleep then.)

The arrows (for actual values) and dotted lines (for possible alternatives) visualise the focus meaning : in (1a) e.g. the actual location of TA in the positive state (*John was asleep*) is opposed to possible alternative locations in the negative state. Rising arrows in (1a-b) indicate positive attitude (events are faster than expected) whereas falling arrows in (1c-d) indicate negative attitude (events are slower than expected). Each adverbial in (1) has a counterpart with the reverse polarity transition (from positive to negative, i.e. the end) in (2) :

(2) a. *al niet meer (?? already no longer)*
b. *al bijna niet meer (?? already almost no longer)*
c. *nog altijd (STILL)*
d. *eindelijk niet meer (?? finally no longer).*

The adverbials *nog* ("still"), *nog niet* ("not yet") and *niet meer* ("no longer"), which are standardly assumed to belong to one and the same paradigm as *al* ("already"), do not play any role in this analysis, but instead are taken to constitute their own paradigm of CONTINUITY expressions, fundamentally different from the focus-paradigms around *al* (Smessaert,1998b). This approach adequately reflects semantic distinctions such as that between *nog niet* ("not yet") and *nog altijd niet* ("still not") on the hand and the semantic similarity between *al* ("already") and *eindelijk* ("finally"), as observed by Van der Auwera (1993) and Van Baar (1997) amongst others. Furthermore, (2) reveals a considerable difference in lexicalisation potential between Dutch and English w.r.t. aspectual focus (ter Meulen & Smessaert, 1994). The graphical representations in (1) can be characterised in terms of the five binary parameters in (3), where "perspective" refers to whether or not the TA lies beyond the PT and "separation" to whether or not the actual and alternative values are located on opposite sides of the polarity transition :

(3)			
	A = "actual polarity"	1 = positive	0 = negative
	B = "transition"	1 = beginning (-/+)	0 = end (+/-)
	C = "perspective"	1 = retrospective	0 = prospective
	D = "attitude"	1 = positive focus	0 = negative focus
	E = "separation"	1 = primary focus	0 = secondary focus

The eight focus adverbials in (1) and (2) thus correspond to a bit-string ABCDE of five binary values (ter Meulen (1995) provides a similar representation, with three binary values, for aspectual auxiliaries) :

(4)						
	1a.	11111	al	2a.	00111	al niet meer
	1b.	01010	al bijna	2b.	10010	al bijna niet meer
	1c.	01001	nog altijd niet	2c.	10001	nog altijd
	1d.	11100	eindelijk	2d.	00100	eindelijk niet meer

If P is the set {A,B,C,D,E} of parameters, then the duality operators which reverse certain polarity values going from one adverbial bit-string to another in (4) are subsets of P. The operator which turns *al* (11111) into *al niet meer* (00111), e.g. is AB, which is a short-hand for {A,B}. If we add the empty set as the identity operator which does not switch any parameter, the set of bit-strings in (4) is closed under all the operators in (5) :

(5) O = {∅, AB, DE, BCD, ACE, BCE, ACD, ABDE}

The set of operators O itself is closed under composition °, defined as symmetric difference (the set-theoretic counterpart of exclusive disjunction):

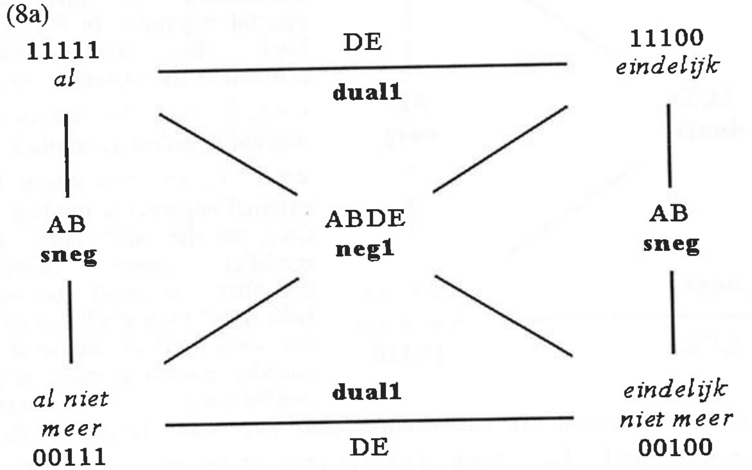
(6) $\forall X \in O, \forall Y \in O\ X°Y \equiv \{Z \in P \mid ((Z \in X) \wedge (Z \notin Y)) \vee ((Z \in Y) \wedge (Z \notin X))\}$

The algebra <O,°> furthermore constitutes a finite Abelian group (° is associative and commutative, ∅ is the identity element, and every operator is its own inverse) with, among others, the seven subgroups listed in (7) :

(7) a. <{∅,AB,DE,ABDE},°>
b. <{∅,AB,BCD,ACD},°>
c. <{∅,AB,ACE,BCE},°>
d. <{∅,DE,BCD,BCE},°>
e. <{∅,DE,ACE,ACD},°>
f. <{∅,BCD,ACE,ABDE},°>
g. <{∅,BCE,ACD,ABDE},°>

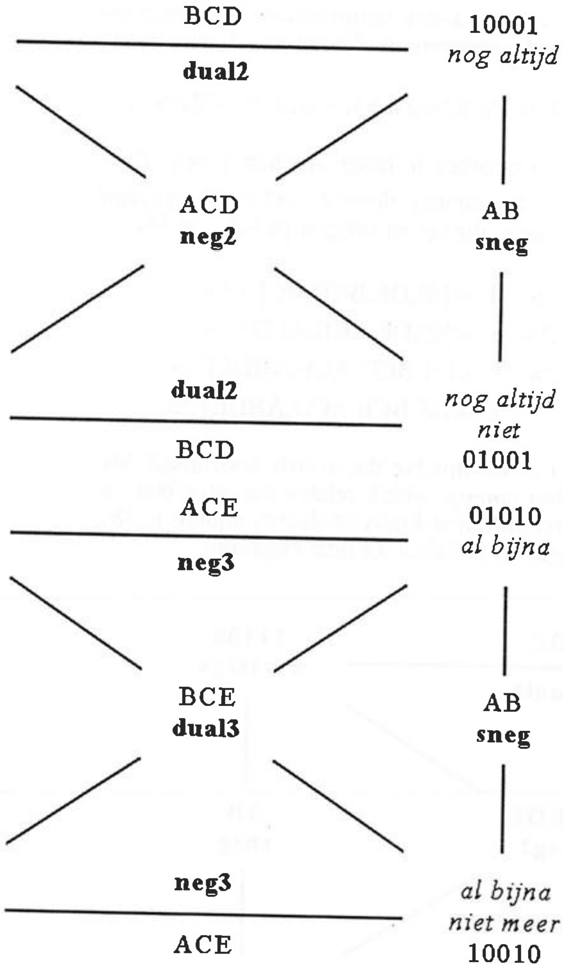
The three operator subgroups in (7a-7c) involve the overtly lexicalised AB-operator of internal or subnegation (*sneg*), which relates the adverbials in (1) and (2). They give rise to three different kinds of duality square in (8), where *neg* stands for external negation and *dual* for dual negation:

(8a)



(8b)

(8c)



The operators in the subgroup (7a) leave the C-parameter intact. Hence, all members of the duality square in (8a) have value 1 for that parameter. The same thing holds in (7b-8b) and (7c-8c) for the E- and D-parameters respectively. As a consequence, all three squares have a counterpart con-sisting of the four adverbials where that particular parameter has value 0.

The dual is encoded lexically in (8a), between *al* and *eindelijk* and in (8b) between *al* and *nog altijd*. In these cases external negation is seen as the combination of dual and internal negation. In Predicate Logic this would mean converting the standard square $<\neg\exists, \exists, \neg\forall, \forall>$, where the internal negation is implicit, to $<\forall\neg, \exists, \exists\neg, \forall>$ where the external negation is implicit. In (8c), on the other hand, the modifier *bijna* *(almost)* lexicalizes external negation (*almost all => not all*; *almost no => some*). Thus the dual is encoded compositionally as the combination of internal negation *niet meer* and external negation *bijna*. This would be equivalent to representing the Predicate Logic square as either $<\forall\neg, \neg\forall\neg, \neg\forall, \forall>$ or $<\neg\exists, \exists, \exists\neg, \neg\exists\neg>$, i.e. with one quantifier and two overt negations.

In the survey in (9) the reference time **t** of the eight focus adverbials is located with respect to the beginning B and the end E of the event. The adverbials above the time axis have primary focus (E=1), whereas those below have secondary focus (E=0). The two adverbials with the same location of **t** have identical ABC-values but opposite DE-values, reflecting the difference between positive focus (D=1) and negative focus (D=0) :

(9)

ACD	-	BCD	AB
neg2	-	**dual2**	**sneg**
01001	11111	10001	00111
altijd niet	*al*	*nog altijd*	*al niet meer*

----t-------B++++t+++++++++++t++++++E------------t-------

ıl bijna	*eindelijk*	*al bijna niet meer*	*eindelijk niet meer*
01010	11100	10010	00100
neg3	**dual1**	**dual3**	**neg1**
ACE	DE	BCE	ABDE

It reveals that *al* and its three duals are all located in the positive area between B and E (their A-parameter equals 1), whereas both the internal and the three external negations are located in a negative area. In other words, the three duality operators, namely DE (dual1), BCD (dual2) and BCE (dual3) are precisely those three members of O in (5) which do not affect the actual polarity encoded in the A-parameter. In (10) the adverbial *al bijna* is taken as the starting point, and here again the three duals have the same polarity, in this case the negative one :

(10)

DE	ACE	ABDE	BCE
dual1	**neg3**	**neg1**	**dual3**
01001	11111	10001	00111
altijd niet	*al*	*nog altijd*	*al niet meer*

----t-------B++++t++++++++++++t++++++E-----------t--------

al bijna	*eindelijk*	*al bijna niet meer*	*eindelijk niet meer*
01010	11100	10010	00100
-	**neg2**	**sneg**	**dual2**
-	ACD	AB	BCD

A number of distributional patterns emerge from (9-10): the odd operators (neg1, neg3, dual1 and dual3) are located on the other side of the time axis, the dual1 characterizes the same reference time, and the neg2 is located on the other side of the same polarity transition. The next step in the analysis is then to design a 3D model (exploiting the self-duality of the tetrahedron) where the adverbials are points in logical space and the duality operations are the edges and diagonals of the polyhedral structure.

References

Van der Auwera, J. 1993. "'Already' and 'still' : beyond duality". *Linguistics and Philosophy* 16: 613-653.

Van Baar, T. 1997. *Phasal Polarity*. (Studies in Language and Language Use 30). Amsterdam, Uitgave IFOTT

De Mey, S. 1994. "'Al' en 'nog' als temporele operatoren". *Tabu* 24(4): 169-186.

Loebner, S. 1990. *Wahr neben Falsch. Duale Operatoren als die Quantoren natuerlicher Sprache*. Tuebingen: Max Niemeyer Verlag.

ter Meulen, A.G.B. 1995. *Representing Time in Natural Language. The Dynamic Interpretation of Tense and Aspect*. Cambridge, Massachusetts, The MIT Press.

ter Meulen, A.G.B. & Smessaert, H. 1994. 'Aspectual focus in English and Dutch', in Peter Bosch & Rob van der Sandt (eds.), *Focus and Natural Language Processing. Proceedings of the Interdisciplinary Conference in Celebration of the 10th Anniversary of the Journal of Semantics.*

Working Papers of the IBM Institute for Logic and Linguistics, Vol. 2 : Semantics, pp. 353-362.
Partee, B.H., ter Meulen, A.G.B & Wall, R.E. 1990. *Mathematical Methods in Linguistics* Dordrecht : Kluwer Academic Publishers.
Smessaert, H. 1998a. 'Adverbials of aspectual focus and negation in Dutch'. to appear in : *Belgian Journal of Linguistics* **12**.
Smessaert, H. 1998b (to appear). *Perspectief en vergelijking. Aspectuele partikels in het Nederlands* (Studies op het gebied van de Nederlandse taalkunde 4, Belgisch Interuniversitair Centrum voor Neerlandistiek). Leuven: Peeters.
Vandeweghe, W. 1992. *Perspectivische evaluatie in het Nederlands : de partikels van de AL/NOG/PAS-groep*. Gent: Koninklijke Academie voor Nederlandse Taal- en Letterkunde.

Humpty Dumpty's Knowledge of Language

or: Why Linguists cannot be Physicalists

Harry Stein - ILLC, Department of Philosophy, University of Amsterdam

Physicalism, the *Oxford Dictionary of Philosophy* informs us, is "the view that everything is constituted of entities taken to be basic by the physical sciences, and that there are no regularities and laws that are independent of the ones that govern the basic physical entities." Three central ideas are combined in this definition: there is a realm of entities that are ontologically basic, there is a particular kind of (causal) law governing this realm and, most importantly, in some fundamental sense these entities and laws exhaust the whole of reality. However, this inclusiveness, which accounts for the attraction of physicalism as a *Weltanschauung*, is also its argumentative Achilles' heel. For in order to refute this view, one only needs to argue that there is at least one salient feature of reality that cannot fit the mould of basic physical entities and laws. Ever since Frege's and Husserl's criticism of psychologism, logical and linguistic phenomena have been thought to provide the focus for such a counter-argument. For language, as we ordinarily conceive of it, is unmistakably a normative phenomenon. We assess a person's linguistic performance in the light of an intricate and many layered framework of norms determining what counts as, e.g., phonological, syntactic or semantical correctness. It is difficult to see how this normative character of language can be accounted for in a physicalistic way. If, for example, one were to locate the basis of a theory of language in some neuro-mental mechanism of individual language users, then it could rightly be observed that the neural aetiology of some concatenation of sounds fails to give us any information about, say, its grammatical correctness or incorrectness. Thus it would seem that a normative phenomenon such as language in principle does not fit a physicalist frame.

The Frege-Husserl objection is a long standing and serious challenge to physicalism. Recently, this classic objection has met with a new response that very effectively seems to circumvent the central problem. Firstly, it is granted Frege and Husserl that our ordinary linguistic concepts have normative features, and it is conceded that such concepts are therefore not explicable in non-normative physical terms. But secondly, and most crucially, it is claimed that these bothersome "normative connotations" of our everyday notions are dispensable when it comes to a scientific study of language. For scientific purposes, it is held, we should rather adopt a notion of language that has been stripped of such features. Such a "cleaned up" notion will still be sufficiently similar to our ordinary concept to qualify as a notion of language, but by lacking normative features it has the advantage of allowing an explication in terms of non-normative, physical facts about language users.

This approach seems to short-circuit the Frege-Husserl objection rather effectively. In this paper, we will further illustrate and assess this general strategy for defending physicalism by turning to the work of Noam Chomsky, who presents us with a detailed example of it. Given the revisionist nature of this response to the Frege-Husserl objection, our main question will be whether the notion that Chomsky presents as an alternative to our ordinary (normative) notion of language can indeed with any plausibility still be regarded as a notion of *language*.

In the second chapter of *Knowledge of Language*, entitled "Concepts of Language", Chomsky attempts to explicate a scientifically fruitful notion of language. The need for such a "technical concept of language", according to Chomsky, stems from the fact that our "intuitive, pretheoretic commonsense notion of language" has a "normative-teleological element" [C86, 16] that stands in the way of a properly scientific approach. Generally speaking, this normative-teleological feature of our ordinary concept refers to our propensity to judge a person's linguistic performance in terms of its correctness or incorrectness in respect to some prior, non-individual standard. It is doubtful, Chomsky claims, whether any coherent account can be given of "language" in this everyday sense and there certainly is no role for such a messy concept in an eventual science of language.

Once the need for a "technical" revision of our ordinary concept of language is established, Chomsky distinguishes two ways in which we may proceed. Firstly, if we regard language as a "construct [that] is understood independently of the properties of the mind/brain" [C86, 20] or as something that "is external to the mind/brain" [C90, 510], we might try to explicate some notion of what Chomsky calls an "External-" or "E-language". It is not necessary to go deeply into Chomsky's assessment of E-languages here. Suffice it to say that Chomsky regards the notion of an E-language as a "useless, perhaps quite senseless concept", that "is of no interest and has no status". It is therefore erroneous to assume "that [the notion of an E-language] is the relevant scientific notion that corresponds to, or should replace, some concept of ordinary language" [C90, 513].

As an alternative to the notion of E-language, Chomsky presents his own concept of an "Internal-" or "I-language". An I-language, Chomsky tells us, "is the state attained by the language faculty under certain external conditions." [C90, 514] Or, to be more precise and drawing freely on some well known Chomskyan terminology, an I-language is an acquired brain state SL of a module of the brain - the "language device" - this state being described by grammar. The state SL is developed by setting parameters of an initial state S, which is innate and is described by Universal Grammar. Being a functional state of (a part of) a particular person's "mind/brain", an I-language is a mental phenomenon of a purely individual nature, and it is held to be the main causal determinant of a person's linguistic performance. In contrast with statements about E-language or about language in the muddled ordinary sense of the word, "statements about I-language [...] are true or false statements about something real and definite, about actual states of the mind/brain and their components". [C86, 26-7]

So, Chomsky grants that linguistic phenomena in an ordinary, normative sense of the word "language" cannot be explicated in physicalist terms. But that observation, he claims, merely underlines the messy and unscientific nature of our ordinary concept of language. For scientific purposes we would do better to employ a notion of I-language that has been rid of such normative features. In that case, the scientific study of language will be the study of the brain states that are causally productive of people's linguistic behaviour, and we have every reason to expect that linguistics, in this sense, will unproblematically fit in with the other natural sciences.

In order to assess Chomsky's proposal we must ask ourselves whether Chomsky's non-normative notion of I-language is indeed an acceptable revision of our ordinary notion of language. In order not to beg the question against Chomsky, we will not concentrate on such disputed features of language as normativity, but on features about which both

Chomsky and we agree that they should pertain to any notion of language. In particular, our focus will be on the fact that language is a possible object of knowledge; something, whatever it may be, of which it makes no sense to say that anyone ever knows it, certainly cannot be a *language*. Furthermore, if Chomsky's revised notion of I-language is to be an acceptable notion of language, then it should at least be the case that the things Chomsky himself says about knowledge of language actually make sense when using his non-normative concept of an I-language. If they do not, then Chomsky's notion can be ruled out of court; not because it cannot account for our ordinary normative judgements, but because it would make it impossible for Chomsky himself to say the things that he actually says about language. Thus, our criticism will be purely internal.

The question what it is to have knowledge of language has always been of paramount interest to Chomsky. We may summarize Chomsky's account of knowledge of language by means of the following four theses.
* To know a language is not primarily a question of possessing certain skills, but rather of knowing a certain set of linguistic rules and construction principles.
* A person's knowledge of language is largely implicit.
* To have knowledge of language is to be in a particular brain state.
* A person's knowledge of language is the main causal determinant of his linguistic production.

All of these claims are controversial. Still, given that our criticism is internal, we shall not dispute any of them. Since Chomsky dismissed both language in the ordinary sense and language in the sense of E-language, the object of our knowledge of language in a scientifically salient sense can only be knowledge of I-language. And indeed, we find Chomsky making the explicit claim that: "It is natural to take L [the language we have knowledge of] to be I-language ... Then, for [a person] H to know L is for H to have a certain I-language." [C86, 23] Thus, a particular person's knowledge of language is knowledge of the particular functional state of the part of his brain that constitutes his language device. As the notion of an I-language is meant to improve on our ordinary concept of language without distorting it beyond all recognition, just so, Chomsky assures us, "the technical concept 'knowledge of I-language' is a reasonably close approximation to what is informally called 'knowledge of language'". [C86, 40]

This sets the stage for a critical assessment of Chomsky's account. According to Chomsky, to have an I-language is to possess a particular brain state, and having knowledge of I-language also consists in being in a particular brain state. Departing from this observation, we will now proceed to construct a dilemma by pressing one single question only: is the state of *having an I-language* identical with the state of *knowing an I-language*, or are these two different states?

Let us start with the latter option which assumes that both states are different and that there is thus a clear distinction between the state of knowledge and the state known. As an example of two states that are related in this way one might think of the following. A psycholinguist can have knowledge of the cluster of mechanisms that are involved in one's grammatical competence and are called the "centre of Broca". Conceiving of this knowledge along Chomskian lines as being itself a brain state, the psycholinguist then has a brain state (knowing the centre of Broca, or "KB") which also represents one of his own brain states (his centre of Broca, or "B"). Of course, these two brain states are different brain states. For, firstly, their role in the total cognitive make-up is very different. The state B is causally effective when it comes to the production of grammatical sentences, while KB is causally effective when it comes to giving lectures in psycholinguistics. Furthermore, B was acquired when learning language as a child, while KB was acquired by following university courses and conducting empirical investigations. Actually, the fact that these states are different is a precondition for claiming that KB instantiates knowledge in the first place. We take it that KB represents B, in which case we must also be able to allow for the possibility that KB only partly represents B, or that it might even misrepresent B in certain respects. This requires that B is distinct from KB, so that B may function as an independent criterion for judging whether, and to what extent KB in fact embodies *knowledge*.

Let us now see whether similar things apply to our knowledge of I-language. The first state we are dealing with is that of the 'I-language'; the acquired functional state of a speaker's language device (or: "I"). The second state would be the one embodying knowledge of this I-language (or: "KI"). On the assumption that these are two different states, it is clear what we mean when we call KI a state of knowledge: it is a state of knowledge to the extent that it truthfully represent the separate state I.

Nevertheless, this idea runs into difficulties as soon as we try to be specific about the causal relevance of both these states and the way in which they are acquired. As far as the I-language is concerned, there are no serious problems. This state is acquired under the influence of the external stimuli we received when learning language as a child, and presently it is the causal basis of our ordinary linguistic performance. Yet, when we regard the state of knowing such an I-language as a second, distinct state, it is quite unfathomable how it was ever acquired and what causal role it might play. One might bring the previous example to mind. There the state of the centre of Broca was acquired during childhood, the knowledge of that state was acquired by attending university classes. Yet, the knowledge of I-language that every speaker is supposed to possess, is certainly not acquired by such academic means. In fact, it is rather mysterious how it could be acquired at all. Secondly, and more importantly, it is difficult to see what bearing this knowledge of I-language could have on one's linguistic performance. In the previous case, the state of the centre of Broca was relevant to one's grammatical performance. Here, the I-language plays a similar role. But knowledge of the centre of Broca, though necessary for treating aphasics, is irrelevant to whatever role the centre of Broca itself might play in linguistic performance, and the lack of such expert knowledge in no way impairs one's actual grammatical performance. By the same token, if knowledge of language were to be a state different from the I-language, it would be perfectly possible for a person to have an I-language and to manifest this in his linguistic performance, while still utterly lacking any knowledge of this I-language, just as he might exercise his centre of Broca without having any knowledge of its construction. So, it is hard to see what causal role our knowledge of I-language is to play if it is a state different from the I-language.

This allows us to formulate the first horn of our dilemma.

(1) When the state of *having an I-language* and the state of *knowing an I-language* are two different states, then:

a. there is an independent criterion to give substance to the knowledge claim, but,

b. it is quite mysterious how one has acquired one's knowledge of language, and

c. knowledge of language is of no (causal) relevance to one's production of language.

Now, since knowledge of language is regarded by Chomsky as the most important causal determinant of our linguistic performance, this outcome is obviously not in accord with Chomsky's claims. Thus, we must look into the second possibility and assume that there is a single state of *having* or *knowing* an I-language.

In that case, the problems about the acquisition and causal relevance of our knowledge of language are solved immediately. After all, we have already seen how to answer these questions in regard to the I-language and on the assumption that both states are identical these answers now simply carry over to our knowledge of language. Yet, a different problem arises. To identify the state of knowledge with the state known effectively pre-empts the possibility of there being a standard which this knowledge has to meet in order qualify as knowledge in the first place. Since the state of the I-language that is known, and the state of knowing it are identical, a change in one's "knowledge" is by definition also a change in one's I-language and if one's I-language were to change, one's "knowledge of I-language" would by definition automatically change accordingly. Thus one's "knowledge of language" is by definition - and therefore gratuitously - complete and perfect.

This situation, it should be noted, is completely due to the identification of the state of knowledge with the state that is being known. It does not spring from the particular mentalist conception of "knowledge as a brain state" that we had granted Chomsky. The previous Broca-example makes this clear. There we also regarded the possession of knowledge as the possession of a particular brain state. But because the object of this knowledge was a different, independent state, we had a criterion for saying that this state of knowledge represents, misrepresents or partially represents something, and we could saliently talk about an eventual increase or decrease of such knowledge. Yet, when we identify both states, we are banned from saying such things about one's knowledge of language. In that case, one's knowledge of language cannot increase or be perfected, nor can one lack such knowledge - one can only change from a state of perfect knowledge of one (I-)language, to a state of equally perfect knowledge of a different one. But obviously, where one cannot possibly be said to lack knowledge of language, one cannot really possess it in any salient sense either. Actually, such a use of the word "knowledge" bears no conceivable relation to our ordinary employment of that term and Chomsky's previous claim that "the technical concept 'knowledge of I-language' is a reasonably close approximation to what is informally called 'knowledge of language'" would in this case be clearly violated.

Thus we arrive at the second horn of our dilemma:

(2) When the state of *having an I-language* and the state of *knowing an I-language* is one and the same state, then:

a. there are no problems regarding the acquisition and causal role of this state, but,

b. there are no longer any criteria which this "state of knowledge" would have to meet in order to qualify as knowledge in the first place, and thus,

c. our ordinary concept of knowledge is inapplicable here or gets distorted beyond all recognition.

So, if knowledge of language is regarded as knowledge of I-language we are faced with an awkward dilemma. Either we regard the state of knowledge of I-language and the state of having an I-language as two different brain states. In that case, knowledge of language is no longer a causal determinant of linguistic competence. Or we take both states to be identical and the idea that we have knowledge of I-language gets robbed of any content whatsoever. This signals the demise of Chomsky's attempt to meet the Frege-Husserl objection by presenting us with a non-normative, scientific revision of our ordinary normative notion of language. For either our knowledge of such a "language" cannot possibly fulfil the role that Chomsky assigns to it, or the notion of "I-language" cannot with any plausibility qualify as a notion of language at all.

In order to generalize our findings, and to shed some light on the relation between language and the brains states possessed by an individual, we will conclude by saying a few words about the second "successor concept" mentioned by Chomsky - that of an "E-" or "external language". If we were to adopt the notion of an E-language, then the object of a person's knowledge of language would be a public language, and not one of that person's own brain states. In that case, one might of course still conceive of the speaker as having a language device that can structurally be characterized by a grammar. Furthermore, it could be claimed that this state of the language device constitutes knowledge of E-language to the extent that the grammar characterizing the speaker's internal state matches the grammar of the E-language. Sticking to Chomsky's terminology of I- and E-language, one could say that by having an I-language, a person can have knowledge of an E-language. Thus, in this case 'having an I-language' and 'having knowledge of language' might also be one and the same state. Yet, the crucial difference with Chomsky is that 'knowledge of language' is now 'knowledge of E-language', and the structure of the public E-language, which is prior and independent of a single person's I-language, determines whether his I-language indeed constitutes knowledge of E-language or not.
So, if the notion of an I-language as the state of an individual's language device can be employed in relation with a prior notion of a public or E-language, then it loses much of its problematic character. "I-language" would then merely be the cluster of brain mechanisms that enables a person to speak a public language, and I-language in that sense might be an interesting subject of psycho-linguistic study.
For the physicalist, however, the introduction of a notion of E-language would be of no use, since there is little hope of defining an E-language without helping oneself to straightforwardly normative notions. In fact, we may now turn the tables on the physicalist's approach. A scientific study of language and of the neuro-causal antecedents of language use does *not* require the abandonment of the normative aspects of language use. On the contrary, this scientific project itself is only possible in as far as it can and does rely on the availability of such normative notions. Indeed, there cannot be a purely physical account of the normative background that is presupposed in such scientific activity. But that fact need not worry or deter the working scientist or linguist. It should merely shy him away from embracing physicalism as the meta-theory of his scientific activity.

Literature

Chomsky, N., 1986, *Knowledge of Language*, New York: Preager .
Chomsky, N., 1988, *Language and Problems of Knowledge*, Cambridge (Mass.): MIT.
Chomsky, N., 1990, "Language and Problems of Knowledge", in Martinich, A.P. (ed.), 1990, *The Philosophy of Language*, Oxford: Oxford University Press.

Indefinites in a type-shifting perspective

Henriëtte de Swart
Utrecht University

Abstract

Indefinite NPs like *a student*, *two cats* have weak, predicative interpretations, and license discourse anaphora. Although NPs like *no student*, *at most two cats* have weak, predicative readings as well, they do not license discourse anaphora. This paper uses type-shifting mechanisms and closure operations to develop a unified analysis of monotone increasing and decreasing indefinite NPs. This leads to some insightful connections between flexible type theory, File Change Semantics/Discourse Representation theory and Dynamic Montague Grammar.

1 Quantification and dynamic binding

The literature on indefinites frequently suggests a close connection between the weak character of these NPs and and the fact that they license discourse anaphora. Partee (1988), De Hoop (1992), Diesing (1992), etc. argue that non-quantificational interpretations lead to weak, predicative readings, and the introduction of discourse referents. Their proposals run into problems when we bring mon ↓ NPs into the picture. Both monotone increasing and decreasing indefinites have weak readings, and are felicitous in existential contexts (1). However, unlike mon ↑ indefinites, mon ↓ indefinites do not license discourse anaphora (2):

(1) a. There is a cat/ no cat/ *the cat/ *every cat/ *neither cat in the garden

b. There are cats/ two cats/ many cats/ at most two cats/ *the cats/ *all cats/ *most cats in the garden

(2) a. A student$_i$ called. She$_i$ had a question about the exam

b. No student$_i$ called. # She$_i$ had a question about the exam

The aim of this paper is to develop a unified account of mon ↑ and ↓ indefinite NPs, which accounts for the two paradigms in (1) and (2).

Following De Hoop (1992), McNally (1995), and Van Geenhoven (1996), I defend the view that weak readings of indefinite NPs are based on a well-formed predicative interpretation of type $\langle e,t\rangle$. In this paper, I explore two ways in which we can combine an NP of type $\langle e,t\rangle$ with a VP also of type $\langle e,t\rangle$. One option is to shift the NP back to a type $\langle\langle s,\langle e,t\rangle\rangle,t\rangle$ expression (section 2). Alternatively, we can combine the predicative NP and the VP by means of some other mode of composition than function application (section 3). The type-shifting perspective provides insightful connections between this predicative type and the analyses of indefinites developed by Kamp (1981) and Heim (1982) on the one hand, and Groenendijk and Stokhof (1990, 1991) on the other (section 4).

2 From properties to generalized quantifiers

2.1 Type-shifting operations

In Partee's (1987) type-theoretical framework, quantificational NPs are defined as those NPs which only have a denotation of type $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$. Non-quantificational NPs have denotations in the domain of expressions of type e ('referential') or $\langle e, t\rangle$ ('predicative') as well as of type $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$ ('quantificational'). Type-shifting principles mediate between the different denotations of an NP. One of the natural type-shifting operations Partee discusses is the mapping BE relating generalized quantifier denotations and predicative interpretations:

(4) BE: $\lambda\mathcal{P}\,\lambda x\,({}^{\vee}\mathcal{P}({}^{\wedge}\lambda y\,[y = x]))$
where $\mathcal{P}$ corresponds with a variable of type $\langle s, \langle\langle s, \langle e, t, \rangle\rangle, t\rangle\rangle$

BE finds all the singleton sets in the generalized quantifier denotation and collects them into a set. Definite and indefinite NPs have well-formed predicative interpretations, for instance:

(5) a student $\rightsquigarrow_{BE}$ BE(a student)
$\lambda Q\,\exists z\,(\text{Student}(z)\ \wedge\ {}^{\vee}Q(z))\ \rightsquigarrow_{BE}$
$\lambda\mathcal{P}\,\lambda x\,({}^{\vee}\mathcal{P}({}^{\wedge}\lambda y\,[y = x]))\,({}^{\wedge}\lambda Q\,\exists z\,(\text{Student}(z)\ \wedge\ {}^{\vee}Q(z)))$
$= \lambda x(\text{Student}(x))$

In order to go back and forth between different NP denotations, it is useful to look at the inverse of type-shifting operations. We can wonder for which determinator denotations DET it is true that BE(DET(P)) = P. The derivation in (5) shows that the answer to this question is *a*. Furthermore, we can ask is which determinator denotation DET guarantees that DET(BE(NP)) = NP. Partee points out that it is impossible to give a general answer to this question, because we lose information with the application of BE. In particular, $\text{BE}(\text{NP}_1) = \text{BE}(\text{NP}_2)$ for every NP_1 and NP_2 which contain the same singleton sets in their denotation. Any attempt to recover the original generalized quantifier denotation on the basis of the union of these singleton sets is thus doomed to fail. Although Partee's observations are correct for the general case, it turns out to be possible to define inverse operations for subclasses of NPs if we do not just look at the set of individuals which result from the application of BE, but we take into consideration the monotonicity properties of the underlying NP.

2.2 Existential insertion

For monotone increasing NPs, the insertion of an existential quantifier ($\exists$I) is the appropriate way to restore the original generalized quantifier denotation:

(6) For mon $\uparrow$ NPs, $\exists$I(BE(NP)) = NP, where $\exists$I is defined as follows:
$\exists$I: $\lambda P\,\lambda Q\,\exists\gamma\,({}^{\vee}Q(\gamma)\ \wedge\ {}^{\vee}P(\gamma))$

(7) BE(a genius) $\rightsquigarrow_{\exists I}$ a genius
λx Genius(x) $\rightsquigarrow_{\exists I}$ $\lambda P\, \lambda Q\, \exists \gamma\, ({}^{\vee}Q(\gamma) \wedge {}^{\vee}P(\gamma))({}^{\wedge}\lambda x \text{ Genius}(x))$
$= \lambda Q\, \exists x\, ({}^{\vee}Q(x) \wedge \text{Genius}(x))$

$\exists$I is of type $\langle\langle s, \langle e, t\rangle\rangle, \langle\langle s, \langle e, t\rangle\rangle, t\rangle\rangle$, i.e. the type of a determiner denotation (cf. Winter 1997). The insertion of an existential quantifier accounts for the intuition that the predicative interpretation of a mon $\uparrow$ NP describes a 'minimal' property. E.g. in order to verify *at least three students*, four or more is also allowed.

2.3 Universal insertion

$\exists$I cannot be used to recover the generalized quantifier denotation of mon $\downarrow$ NPs, because the predicative interpretation of these NPs describes a 'maximal' property. *At most five students* implies that four or less is also admissible. Maximality naturally suggests an operation of universal insertion ($\forall$I):

(8) For mon $\downarrow$ NPs, $\forall$I(BE(NP)) = NP, where $\forall$I is defined as follows:
$\forall$I: $\lambda P\, \lambda Q\, \forall \gamma\, ({}^{\vee}Q(\gamma) \rightarrow {}^{\vee}P(\gamma))$

(9) BE(no genius) $\rightsquigarrow_{\forall I}$ no genius
$\lambda x \neg$ Genius(x) $\rightsquigarrow_{\forall I} \lambda P\, \lambda Q\, \forall \gamma\, ({}^{\vee}Q(\gamma) \rightarrow {}^{\vee}P(\gamma))({}^{\wedge}\lambda x \neg \text{ Genius}(x))$
$= \lambda Q\, \forall x\, ({}^{\vee}Q(x) \rightarrow \neg \text{ Genius}(x))$

3 From properties to propositions

3.1 Existential closure

If we give NPs a family of types as their interpretation, we have to determine in which contexts which denotation is required, and how the NP combines with other expressions. Kamp (1981) and Heim (1982) show that a interpretation of the indefinite NP in terms of a (static) existential quantifier does not account for the discourse anaphor in (10):

(10) A student$_i$ called John$_j$. She$_i$ had a question about the exam

They interpret indefinite NPs as non-quantificational expressions which introduce a new discourse referent, and translate as free variable. In a type-theoretical approach, their ideas are close to an interpretation of indefinites as expressions of type $\langle e, t\rangle$, which denote properties (cf. De Hoop 1992, McNally 1995, Van Geenhoven 1996). Of course, combination of a predicative NP of type $\langle e, t\rangle$ with a VP also of type $\langle e, t\rangle$ does not lead to an expression of type t by means of function application. Accordingly, we have to consider other modes of composition. Carlson (1978) and Van Geenhoven (1996) suggest that when a predicative NP combines with a VP, the NP restricts the individuals that the predicate applies to, and the predicate introduces the necessary quantificational force. The following definition of local existential closure (∃C) is appropriate for predicative NPs derived from monotone increasing NPs:

(11) ∃C for predicative NPs derived from monotone increasing NPs
For Q a predicate of type $\langle s, \langle e, t\rangle\rangle$, which operates on individuals, and P_{min} a predicative NP of type $\langle s, \langle e, t\rangle\rangle$, which denotes a minimal property derived from a monotone increasing NP, the combination of Q and P_{min} introduces existential quantification over the variable of the NP argument:
∃C: $\lambda x\, {}^{\vee}Q(x)(P_{min}) = \exists x\, ({}^{\vee}Q(x) \wedge {}^{\vee}P(x))$

3.2 Universal closure

Monotone decreasing indefinites do not license discourse anaphora:

(12) No train$_i$ arrived. # It$_i$ was late again

Accordingly, Heim restricts existential closure to indefinite NPs which introduce a new discourse referent. Monotone decreasing NPs do not belong to that category, so they translate as genuine quantifiers. This proposal has some undesirable consequences for the unified treatment of indefinites. Although *no train* shares with *every student* the property of not licensing discourse anaphora, it shares a number of other interesting semantic properties with *a student*. Monotone increasing and decreasing indefinites both have well-formed predicative interpretations, and show a contrast between weak (cardinal) and strong (generic, partitive, proportional) readings. Diesing (1992) and De Hoop (1992) show that for monotone increasing indefinites, we can relate that contrast to non-quantificational (type $\langle e, t\rangle$) versus quantificational (type $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$) interpretations. If monotone decreasing indefinites always translate as generalized quantifiers, we have to develop a different account for the weak/strong readings of monotone decreasing indefinites. Such an approach would miss a generalization.

The predicative interpretation of a monotone increasing NP describes a minimal property, which triggers existential quantification over the relevant variable. The predicative interpretation of a monotone decreasing NP describes a maximal property, which triggers a universal closure operation (∀C):

(13) ∀C for predicative NPs derived from monotone decreasing NPs
For Q a predicate of type $\langle s, \langle e, t\rangle\rangle$, which operates on individuals, and for P_{max} a predicative NP which denotes a maximal property derived from a monotone decreasing NP, the combination of Q and P_{max} introduces universal quantification over the variable of the predicative NP:
∀C: $\lambda x\, {}^{\vee}Q(x)(P_{max}) = \forall x\, ({}^{\vee}Q(x) \rightarrow {}^{\vee}P(x))$

(14) No train arrived
$\lambda x\ \mathrm{Arrive}(x)({}^{\wedge}\lambda y \neg\, \mathrm{Train}(y)) = \forall x\, (\mathrm{Arrive}(x) \rightarrow \neg\, \mathrm{Train}(x))$

3.3 Dynamic binding

∀C and ∃C are local closure operations, so the scope of the quantifier is restricted to the sentence in which it is introduced. At this point then, the local closure operations do not yet account for the different dynamic binding properties of these expressions, illustrated in (10) and (12). It is here that the proposals made by Groenendijk and Stokhof (1990, 1991) come in extremely useful. Groenendijk and Stokhof develop dynamic versions of predicate logic and Montague grammar in which the existential quantifier gets an externally 'dynamic' interpretation. As a result, an anaphoric pronoun in a later sentence can refer to the same individual. Unlike the existential quantifier, the universal quantifier is externally static, and its scope does not extend beyond the sentence in which it occurs.

Obviously, the insertion operations defined in section 2 combines well with the dynamic approach, because the inverse relations of BE return a generalized quantifier denotation. The closure operations can incorporate the same insight. If we assume that ∃C involves a dynamic existential quantifier, whereas ∀C is an externally static universal quantifier, we correctly predict that mon ↑ indefinites license discourse anaphora, whereas mon ↓ indefinites do not.

4 Insertion and closure: a comparison

Some empirical applications of the type-shifting system are presented in de Swart (1996). Here I focus on the use of flexible type theory as a means to establish connections between frameworks. The purpose of ∃C and ∀C was to define alternative modes of composition for combinations of a weak subject NP and a regular VP, both of type $\langle e,t\rangle$. The closure operations are defined in such a way that C((BE(NP))(VP)) = NP(VP). Given that we defined the insertion operations in such a way that I(BE(NP)) = NP, we know that C((BE(NP))(VP)) = I((BE(NP))(VP)). This means that the closure operations ∃C and ∀C can be derived from the introduction mechanisms ∃I and ∀I, and do not need to be stipulated independently in the grammar. We might say that the closure operations take a short cut: instead of shifting back a predicative NP of type $\langle e,t\rangle$ to its generalized quantifier denotation, and then applying this function to the VP in order to build a proposition of type t, the closure operation directly maps the combination of two expressions of type $\langle e,t\rangle$ onto a proposition of type t. The 'short way' and the 'long way' should lead to the same interpretation, which explains why both the closure operation and the insertion mechanism are dependent on the monotonicity properties of the underlying generalized quantifier.

The development of Dynamic predicate logic and Dynamic Montague Grammar by Groenendijk en Stokhof (1990, 1991), and others shows that the licensing of discourse anaphora need not be in the way of an interpretation of indefinite NPs as generalized quantifiers. An important advantage the dynamic framework claims is that the semantic properties of NPs such as they have been studied in the framework of generalized quantifier theory are preserved in a dynamic theory of discourse anaphora based on indefinite NPs of type $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$. The relations I establish in this paper between closure operations and introduction mechanisms suggest that a reformulation of File Change Semantics or Discourse Representation Theory in a type-shifting perspective can derive this result just as well.

5 References

G. Carlson (1978). *Reference to kinds in English*, New York: Garland.

M. Diesing (1992). *Indefinites*, Cambridge MA: MIT Press.

J. Groenendijk and M. Stokhof (1990). 'Dynamic Montague grammar', in: L. Kálman and L. Pólos, L. (eds.). *Papers from the second symposium on logic and language*, Budapest: Akademiai Kaido, pp. 3–48.

J. Groenendijk and M. Stokhof (1991). 'Dynamic predicate logic', *Linguistics and Philosophy* 14, pp. 39–100.

I. Heim (1982). *The semantics of definite and indefinite NPs*, PhD. diss. University of Massachusetts, Amherst.

H. de Hoop (1992). *Case configuration and noun phrase interpretation*, PhD. diss. University of Groningen.

H. Kamp, H. (1981). 'A theory of truth and semantic representation', in: J. Groenendijk, Th. Janssen and M. Stokhof (eds.). *Formal methods in the study of language*, Amsterdam: Mathematisch Centrum. Reprinted in J. Groenendijk, T. Janssen and M. Stokhof (eds.) (1984). *Truth, interpretation and information*, Dordrecht: Foris, pp. 1–41.

McNally, L. (1995). 'Bare plurals in Spanish are interpreted as properties', in: G. Morrill and D. Oehrle (eds.). *Formal grammar*, Universitat Politécnica de Catalunya, pp. 197–222.

B. Partee (1987). 'Noun phrase interpretation and type-shifting principles', in: J. Groenendijk, D. de Jongh, and M. Stokhof (eds.). *Studies in Discourse Representation theory and the theory of generalized quantifiers*, Dordrecht: Foris, pp. 302–323.

B. Partee (1988). 'Many quantifiers', in: Proceedings of ESCOL 5, Columbus: Ohio State University.

H. de Swart (1996). 'Scope ambiguities with negative quantifiers', in: K. von Heusinger and U. Egli (eds.). *Proceedings of the workshop on reference and anaphorical relations*, Konstanz: Fachbereich Sprachwissenschaft, Arbeitspapier nr 79, University of Konstanz, pp. 145–164.

V. Van Geenhoven (1996). *Semantic incorporation and indefinite descriptions*, PhD. diss. University of Tübingen.

Y. Winter (1997). 'Choice functions and the scopal semantics of indefinites, *Linguistics and Philosophy* 20, 399–466.

Reconstruction, anaphora, and pronouns as identity maps

Anna Szabolcsi
UCLA and HUJ

This paper examines how pronouns interpreted as identity maps fit into a framework of dynamic semantics. There are at least two reasons why this question is interesting for the linguist.

First, Jacobson (1997) has argued, with reference to classical sentence-internal test cases like antecedent contained deletion, functional readings, i-inside-i, etc. that the identity map interpretation of pronouns is preferable to the the traditional free variable interpretation. If Jacobson's arguments are convincing, and I believe they are, then it is imperative to extend this theory to cross-sentential anaphora.

Second, this proposal has a further advantage that is not explored in Jacobson's papers: it makes "reconstruction" costless. Chierchia (1995) points out that in free variable theories, reconstruction poses the same logical problem as cross-sentential anaphora. It is of some interest to compare what logical apparatus these require on the present proposal.

<u>Pronouns as identity maps</u>

This is how the basic proposal works. <u>Him</u> is interpreted as λx.x and bears the syntactically inert functor category np|np, which can only be applied to. The Geach rule enables <u>saw</u> and <u>Mary</u> to combine with it:

(1)

Mary		saw		him
s/(np\s)	geach	(np\s)/np	geach	np|np
(s|np)/((np\s)|np)		((np\s)|np)/(np|np)		
		(np\s)|np		
s|np				

The resulting clause bears the category s|np and is accordingly interpreted as a property, λx[saw(x)(m)].

Crucially, this interpretation is invariant: it supports both the bound variable and the deictic uses of the pronoun, and on the deictic use, it eliminates the traditional ambiguity between different free variables. If <u>him</u> is deictic, the property λx[saw(x)(m)] is predicated of a contextually salient individual. If <u>him</u> is to be bound by a c-commanding quantifier, a silent combinator "z" applies to a higher verb and identifies two argument slots. "z" incorporates Geach and the Duplicator, λf λx[fxx]:

(2) Everyone/i thinks Mary saw him/i:

z-think = λg λv[think(gv)(v)]

z-think(Mary saw him) = λgλv[think(gv)(v)](λx[saw(x)(m)]) = λv[think(saw(v)(m))(v)]

Everyone z-thinks Mary saw him = ∀y[think(saw(y)(m))(y)]

Identity maps and reconstruction

I will not review Jacobson's extensive empirical arguments in favor of this set-up but proceed directly to "reconstruction." Suppose the clause with the pronoun is topicalized:

(3) If it/i is hungry, a cat/i meows.

As Chierchia (1995) points out, binding into topics is traditionally handled using reconstruction: since a cat does not c-command the pronoun, the clause if it is hungry needs to be reconstructed into its scope. If pronouns are interpreted as free variables, this would seem like an illegitimate move: it is free in the topic position and bound in the reconstructed position. Chierchia invokes a new logical device, abstraction over assignments, that DMG introduced to solve a comparable problem arising in cross-sentential anaphora. He argues that the fact that this device proves useful in reconstruction constitutes an empirical argument in favor of DMG, as compared to DRT, for instance.

But notice that Jacobson's theory handles reconstruction without any addition whatsoever. For simplicity, this is illustrated using the relevant alternative bracketing of (2), available due to the associativity of categorial grammar. Since him was never a free variable, there is no lambda-conversion problem:

(4) [Everyone/i thinks] [Mary saw him/i]:

everyone z-thinks = $\lambda g \forall y[\text{think}(gy)(y)]$

Everyone z-thinks Mary saw him =

$\lambda g \forall y[\text{think}(gy)(y)](\lambda x[\text{saw}(x)(m)]) = \forall y[\text{think}(\text{saw}(y)(m))(y)]$

This suggests that the choice between DMG-style and DRT-style theories of anaphora should be made independently of the issue of reconstruction. This is a welcome result, since abstraction over assignments is a technical, rather than conceptual, feature of dynamic semantics.

Cross-sentential anaphora in DMG

It remains to be seen how the identity map theory of pronouns can be extended to cross-sentential anaphora. In this paper I simply adopt the general assumptions of DMG. That is, I assume a compositional theory in which an indefinite is an existential quantifier with a continuation variable in its scope, conjunction is interpreted as composition, and pronominal anaphora is captured by interpreting the pronoun as a variable bound by the antecedent. In addition, DMG initially interprets pronouns as free variables (discourse markers); this is an assumption that I will abandon, but it is useful to recap how it works:

(5) a. A man came in: $\lambda p \exists x[\text{man}(x) \,\&\, \text{came}(x) \,\&\, \{x \backslash d\}{}^{\vee}p]$

b. He whistled: $\lambda p[\text{whistle}(d) \,\&\, {}^{\vee}p]$

c. A man/d came in. He/d whistled:

$\lambda q[\lambda p\exists x[man(x) \& came(x) \& \{x\backslash d\}{}^{\vee}p](^{\wedge}\lambda p[whistle(d) \& {}^{\vee}p](q))]$

$= \lambda q[\exists x[man(x) \& came(x) \& \{x\backslash d\}[{}^{\vee\wedge}whistle(d) \ \& {}^{\vee}q]]]$

$= \lambda q[\exists x[man(x) \& came(x) \& whistle(x) \& \{x\backslash d\}{}^{\vee}q]]$

Abstraction over assignments (^) allows us to bring the free variable pronoun into the scope of the quantifier. The indefinite's translation contains a state (=assignment) switcher {x\d}. This effectively associates a free variable d with the indefinite, though unlike DRT, solely for binding purposes. When {x\d} is prefixed to a proposition p, it sets the discourse marker d in p to the value of x, the variable bound by the existential quantifier. The pronoun gets bound iff its discourse marker is also d.

Identity maps and cross-sentential anaphora: an overview

The simplest way to extend Jacobson's theory to cross-sentential anaphora might be this. Retain the DMG treatment of A man came in. Assume that {x\d} makes d contextually salient. He whistled starts out as a property. Assimilate the anaphoric use to the deictic use and apply this property to d. From here on, proceed as in (5).

This extension may be viable, but it is not particularly interesting; I will not pursue it here. Instead, I observe that A man came in in (5) and Everyone z-thinks in (4) are quite parallel: both contain (i) a quantifier, (ii) a slot for an incoming clause in the quantifier's scope, and (iii) a binding device that links a pronoun in the incoming clause to the quantifier. In (5), the binding device is the state switcher {x\d} (aided by ^/ˇ); in (4), it is the combinator "z". The parallelism suggests that, with pronouns as identity maps, cross-sentential anaphora does not require any machinery beyond what is needed for sentence-internal binding. Namely, both ^/ˇ and {x\d} can be eliminated in favor of "z".

I call the above "binding built in". In the next section I develop it in some detail and show that it is in principle viable, but the combinatorics is overly complicated. I therefore propose another solution, one that does "binding on the fly". This involves reinstating some of the DMG machinery. Specifically, to reduce combinatory complexity, I reintroduce state-switchers, but abstract over their discourse marker component. The conclusion is that reconstruction is in fact easier than anaphora.

Lack of space prevents me from discussing related work by Ben-Shalom, Hepple, Dekker, Zimmerman, and myself.

Cross-sentential anaphora with "binding built in"

Assume, with Jacobson, that pronouns are identity maps. Assume, with DMG, that sentences are associated with context change potentials. But, for the continuation, do not use a propositional variable p and a state switcher {x\d}, as in (5). Instead, use a property variable with an argument bound by the indefinite's quantifier or the pronoun's lambda:

(6) A man came: $\lambda f\exists x[man\text{-}came(x) \& f(x)]$

(7) A woman left: $\lambda f\exists z[woman\text{-}left(z) \& f(z)]$

(8) He/She was tall: $\lambda f \lambda y[\text{tall}(y) \ \& \ f(y)]$

Here, the combinator "z" comes built into the interpretations of indefin-ites and pronouns. Its effect is different in the two cases, though. In (6)-(7), f(x) and f(z) let the indefinites bind pronouns; on the other hand, in (8), f(y) passes on the binding ability of the pronoun's binder.

The interpretations given in (6)-(8) are invariant. Whether an indefinite actually binds an incoming pronoun does not depend on its or the pronoun's interpretation. It depends on how the two sentences are put together, specifically, on whether and how they are Geached before getting dynamically conjoined, i.e. composed (•):

(9) A man/i came. He/i was tall. **(6) • (8)**

$\lambda f \exists x[\text{man-came}(x) \ \& \ f(x)] \circ \lambda f \lambda y[\text{tall}(y) \ \& \ f(y)] =$

$\lambda g \exists x[\text{man-came}(x) \ \& \ \text{tall}(x) \ \& \ g(x)]$

(10) A man/i came. She/j was tall. **GEACH(6) • IN-GEACH(8)**

$\lambda r \lambda v \exists y[\text{man-came}(y) \ \& \ r(v)(y)] \circ \lambda r \lambda z \lambda d[\text{tall}(z) \ \& \ r(z)(d)] =$

$\lambda k \lambda v \exists y[\text{man-came}(y) \ \& \ \text{tall}(v) \ \& \ k(v)(y)]$

(11) A man/i came. A woman/j left. **(6) • GEACH(7)**

$\lambda f \exists x[\text{man-came}(x) \ \& \ f(x)] \circ \lambda r \lambda v \exists y[\text{woman-left}(y) \ \& \ r(v)(y)] =$

$\lambda r \exists x[\text{man-came}(x) \ \& \ \exists y[\text{woman-left}(y) \ \& \ r(x)(y)]]$

Two problems might seem to threaten the viability of this proposal. First, if the indefinite ever needs to bind more than one pronoun in one swoop, (6)-(7) do not suffice and $\lambda r \exists x[\text{man-came}(x) \ \& \ r(x)(x)]$, etc. must be added. But this need actually does not arise. As Jacobson (1997) notes, the pronouns can be "merged" first even in (12), where the two instances of him do not c-command each other:

(12) A man/i came. The woman who saw him/i greeted him/i.

The second problem is that negation makes an indefinite in its scope inaccessible for subsequent anaphora, but it does not affect a pronoun's ability to pass binding on:

(13) A man/i came. [I do] not [think that] a woman/j saw him/i.
He/i / she/*j was tall.

This problem is solved by defining externally static operators that give just the desired result. The version of negation suitable for a sentence with one indefinite and one pronoun is this:

(14) a. $\text{NOT} = \lambda Y \lambda f \lambda z[\neg(Y(\lambda x \lambda y.T)(z)) \ \& \ f(z)]$

b. not...a woman saw him =

$\text{NOT}(\lambda r \lambda x \exists y[\text{woman}(y) \ \& \ \text{saw}(x)(y) \ \& \ r(x)(y)])$

$= \lambda f \lambda z[\neg \exists y[\text{woman}(y) \ \& \ \text{saw}(z)(y) \ \& \ T] \ \& \ f(z)]$

The present proposal is very attractive in that it handles cross-sentential anaphora without any new binding trick. But it is time to admit that its combinatorics is very costly.

This can be seen already from examples that do not involve any binding. Take a text with n independent dramatis personae (indefinites or currently free pronouns). The continuation variable of such a text will be a n-place function. An incoming clause with the n+1th new player must be Geached n times, to adjust its type. This contradicts the intuition that at least the addition of new players to a discourse should be effortless.

Naturally, the above complexity carries over to binding. Suppose the incoming pronoun is to be bound by the ith member of a sequence of n players. The clause that contains it also needs to be Geached n times; in addition, the correct subspecies of Geach needs to be chosen to ensure that the right binder is picked. The examples in (9)-(11) are deceptively simple, because they involve at most two distinct players.

Thus, I will abandon this proposal, despite its initial appeal.

Cross-sentential anaphora with "binding on the fly"

The simplest thing would be to start with (15)-(16) and let all binding happen in the course of dynamic conjunction, when the need arises:

(15) A man came: $\lambda p \exists x[\text{man-came}(x) \,\&\, p]$

(16) He/she was tall: $\lambda p \lambda y[\text{tall}(y) \,\&\, p]$

In other words, what we want is for a duplicator to apply to A man came when a pronoun in the continuation is anaphoric to it. Unfortunately, since x is bound in (15), no duplicator can access it. Thus, replace (15) by (17). (17) reintroduces DMG's state switcher, but with the "discourse marker" abstracted over. (I use scare quotes because these variables have no special status now.)

(17) A man came: $\lambda p \lambda v \exists x[\text{man-came}(x) \,\&\, \{x \backslash v\}p]$

This facilitates duplication, because we will now have two lambda-bound arguments. One corresponds to the indefinite: it is the abstracted-over "discourse marker." The other corresponds to the pronoun and will be introduced by the Geach-rule:

(18) ... A man came. He was tall: **DUPLICATE(GEACH(17)) • (16)**

$\lambda f \lambda z[\lambda g \lambda y[\underline{\lambda p \lambda v \exists x[\text{man-came}(x) \,\&\, \{x \backslash v\}p]}(gy)](f)(z)(z)] \bullet (16) =$

$\lambda f \lambda z \lambda g \lambda y \lambda v \exists x[\text{man-came}(x) \,\&\, \{x \backslash v\}g(y)](f)(z)(z)] \bullet (16) =$

$\lambda f \lambda z \exists x[\text{man-came}(x) \,\&\, \{x \backslash z\}f(z)] \bullet (16) =$

$\lambda q \lambda z \exists x[\text{man-came}(x) \,\&\, \text{tall}(x) \,\&\, \{x \backslash z\}q]$

Thus, this proposal does involve a new trick (abstraction over the "discourse marker" component of the state switcher). However, this seems more conservative than DMG's abstraction over assignments.

Turning to some details, I propose to compose Duplicate and Geach into a single operation, rather than applying them sequentially, as in (18). (Incidentally, the result is nothing but "z".) The one-step operation "knows" which argument slots have just been created by Geach for incoming pronouns and is thus generalizable to more complex binding patterns, without identifying slots incorrectly:

(19) A man/i met a boy/j/*i. He/i/j/k greeted him/j/i/*k/l.

Likewise, an operation replicating Kamp and Reyle's (1993) summation for split antecedents can be defined as a single combinator applying to the old text before dynamic conjunction:

(20) A man/i met a boy/j. They/i+j hugged.

a. A man met a boy:

$\lambda p\lambda v\lambda u\exists x\exists y[man(x)\ \&\ boy(y)\ \&\ met(x,y)\ \&\ \{x\backslash v\}\{y\backslash u\}p]$

b. sum: $\lambda X\lambda f\lambda a\lambda b[X(\exists n[f(n)\ \&\ n=a+b])(a)(b)]$

c. They hugged: $\lambda p\lambda m[hug(m)\ \&\ p]$

d. sum(21a) • (21c) = $\lambda q\lambda a\lambda b\exists x\exists y[man(x)\ \&\ boy(y)\ \&\ met(x,y)\ \&\ \exists n[hug(n)\ \&\ n=x+y]\ \&\ \{x\backslash a\}\{y\backslash b\}q]$

When no binding is involved, absolutely nothing is needed beyond Jacobson's original sentence-internal binding grammar. We just apply Geach to the old text for each incoming pronoun, exactly as in (1):

(21) ... A man/i came. She/j was tall. **GEACH(17) • (16)**

$\lambda f\lambda z\lambda v\exists x[man\text{-}came(x)\ \&\ \{x\backslash v\}f(z)] \bullet \lambda p\lambda y[tall(y)\ \&\ p] =$

$\lambda q\lambda z\lambda v\exists x[man\text{-}came(x)\ \&\ tall(z)\ \&\ \{x\backslash v\}q]$

To summarize, state switchers eliminate the combinatory complexity that stems from using n-place continuation variables for texts with n players. The number of players is now irrelevant for Geach, and the clause containing the pronoun never needs to be Geached. Likewise, no "pronominal negation" is needed, cf. (14).

Reconstruction versus cross-sentential anaphora

We now see why reconstruction is easier than cross-sentential anaphora. Reconstruction is a sentence-internal process. Thus, it is always possible to build the sentence in such a way that duplication takes place before the intended binder of the pronoun enters the derivation. Recall (3): think can undergo "z" before it combines with every man. On the other hand, due to the problem of complexity, cross-sentential anaphora is better handled by binding on the fly. The latter involves that duplication must be applied to a structure that already contains the intended binder (the indefinite). Hence the need for some extra trick.

References

Chierchia (1995), Dynamics of Meaning. Chicago UP.
Groenendijk & Stokhof (1989), Dynamic Montague Grammar. In Kálmán & Pólos, eds., Logic and Language. Akadémiai, Budapest.
Jacobson (1997), Towards a Variable-free Semantics. Submitted to Linguistics and Philosophy.
Kamp & Reyle (1993), From Discourse to Logic. Kluwer.

Any as a Finian quantifier[1]

Lucia Maria Tovena, ITC–IRST, Trento and Jacques Jayez, EHESS, Paris

1 Facts

In this abstract, we are going to account for the following facts in the distribution of *any*: (a) *any* N is possible in generic sentences, (1), (b) *any* N is odd in descriptive sentences, unless N is characterised by a non–accidental property, (2) and (3), (c) *any* N is odd with *must*–obligations, (4), (d) *any* N is possible with *may*–permissions and with imperatives, (5) and (6), (e) *any* N can behave in many ways like a Negative Polarity Item (NPI), (7), (8) and (9).

(1) Any owl hunts mice
(2) *Mary read any book
(3) Mary read any book (which was on the reading list)/??(which happened to be on her desk)
(4) *Mary must read any book
(5) Mary may read any book
(6) Pick any book
(7) Mary did not read any book
(8) (At most)/*(At least) two students read any book
(9) I am surprised/*glad that you read any book

In spite of the existence of a substantial body of literature on *any*, no general agreement has emerged over the years.[2] Intuitively, the main difficulty is the tension between the appeal of uniformity and the weight of the empirical evidence in favour of two distinct behaviours of *any*, as a P(olarity) S(ensitive) I(tem), which prefers negative or downward monotone contexts and has the logical flavour of $\exists$, and as a F(ree) C(hoice) I(tem) with the flavour of a $\forall$ (Ladusaw 1979, Davison 1980, Carlson 1981). Recent literature offers two main ways of overcoming this problem.

2 The double life of *any*

Recently, the *any*–as–indefinite thesis has regained some vividness. Kadmon and Landman (1993) have proposed that *any* is an indefinite obeying two semantico-pragmatic constraints which are responsible for its distribution. The constraint of *widening* requires that, in *any* N, *any* widens the interpretation of N along (at least) one contextual dimension. So, (1) might be understood as applying to every owl, even the less apt, healthy, etc. The constraint of *strengthening* requires that the *any* N statement entail the corresponding statement without the widening effect. Examples like (2) are bad because this entailment does not hold. The widening paraphrase of (2) is 'Mary read a book of some kind (easy/not easy, pleasant/not pleasant, etc.)' and this paraphrase does not entail 'Mary read a book (a standard one)'. If Mary read a non–standard book (along some semantic dimension), she did not necessarily read a standard book along the same dimension, so the entailment is not necessarily satisfied. Israel (1996) and Lee and Horn (1994) have proposed very similar treatments.

Unfortunately, such approaches are much less convincing when it comes to FC *any*.[3] First, non–accidental modification (cf. (3)) improves definitely examples like (2). The reading of *any* is then clearly the FC one, since, as noted by Dayal (1995), it is possible to insert *almost* or *practically* (*Mary read practically any book which*

[1]This abstract has benefited from comments by Anastasia Giannakidou, Hans Kamp and Ruth Kempson on a previous presentation. Special thanks are due to Ruth Kempson who frequently took the pain to discuss and comment English data. Unfortunately, remaining weaknesses are entirely ours.

[2]See (Tovena 1996) and (Horn 1996) for recent reviews.

[3]Israel seems to point indirectly to this problem in the cryptic footnote (18) of his 1996 paper.

...). A similar remark applies to *must*-obligations. Second, how are we to explain the difference between *must*-obligations and imperatives? If (4) is offending because it means 'Mary must read a book (standard or not)', which may not entail 'Mary must read a standard book' (Kadmon & Landman's account), or not convey an emphatic value (Israel's account), with respect to variants such as *Mary must read a book*, why does the same reasoning not apply to imperatives?

Other recent proposals have attempted to give a unified semantic account without necessarily taking a firm stance towards the issue of the classification of the item. These proposals make extensive use of notions like *veridicality* or *existentiality* (Dayal 1995, Zwarts 1995, Giannakidou 1997). They assume that *any* is basically an existence-repellent determiner: *any* N is semantically licensed precisely in those contexts where one need not suppose that the N-predicate has a non-empty domain. Admissible contexts are those where the existence can be explicitly negated without contradiction (Dayal 1995).[4] Although the veridicality approach seems natural for questions and downward monotone contexts (including negation), we observe that it runs into problems in other cases. It leads to cases of underlicensing, i.e. *any* is wrongly predicted to be impossible (6), overlicensing, i.e. it is wrongly predicted to be possible (10), and indiscrimination, i.e. observations support two competing hypotheses (11).

(10) A psychologist instructing a subject:
That is the room, cards with various shapes are scattered on the floor. You must pick up every/??any square and then push the green button. If there are no squares, push the red one

(11) In that period any foreigner was considered as responsible for the war, ?? but there were no foreigners

According to Dayal's analysis of commands, (6) must be rejected: there will be some card which is picked if the command is executed. Next, (10) does not entail the existence of squares, hence *any* should be acceptable with a universal reading whereas it is not. Last, if (11) is interpreted as ranging over a set of situations (Giannakidou 1997), one cannot discriminate between non-existence and variation. In *some* of these situations the domain of the N-predicate may be empty (non-existence), and/or vary across situations (variation).

3 (yet) Another solution

The solution we propose comes into two parts. First, we assume that, in the current state of knowledge, the choice of an existential or universal value for *any* is a 'hard fact' which may not receive any convincing explanation. Second, within the bounds of these conventionalised restrictions, *any* resists individuation (rather than existence). Intuitively, *any* N is acceptable in a sentence S only when S does not entail that a fixed set of N-objects possesses the property described by the rest of S.

3.1 The restricted ambiguity of *any*

It is of course not sufficient that an interpretation does not emerge to be radically impossible. It could exist at some level of representation and be blocked at some other level by a (set of) constraint(s). We consider an existential or universal interpretation for *any* to be 'impossible' when it does not emerge, although no constraint seems to block it. A more ambitious treatment would probably consider that *any* is systematically ambiguous and the violation of hidden constraints explains the non-emergence of certain readings, but it is beyond the scope of this paper. The only impossibility we assume here is that *any* N may not be universally interpreted whenever (i) it occurs in a context which is usually taken to license PSIs, (ii) N is

[4] A very similar proposal can be found in Carlson (1981). Dayal adds the idea that *any* N may not refer to a fixed set of individuals, but she does not make it the central property.

not modified. In contrast, sentences like *At most two students read any book which was on the reading list* are ambiguous (at least for some speakers) between the $\exists$ and $\forall$ readings. As we will see, other cases (positive descriptive sentences, modals, imperatives) are compatible with the existence of an $\exists$ vs $\forall$ ambiguity.

3.2 The constraint of Non Individuation

For clarity, we decompose our proposal into 3 facets.

1. We follow Kempson (1985) in assuming that the central explanatory factor is that of *dependency*. Specifically, in a quantification of form $\mathcal{Q}_{any}$ N P, the objects which satisfy P do it *in virtue of being* N-objects. This is reminiscent of Fine's work (Fine 1985, 1995) on dependency. Borrowing the notation of Fine (1995), we have in such cases: $\Box_{\mathrm{N}\,\vee P}\forall x(\mathrm{N}(x) \Rightarrow P(x))$, or, 'every N-object is a P object in virtue of the nature of the objects which are N or P'.

2. We acknowledge the 'modal' (Dayal 1995) character of *any*, by requiring that the dependency between P and N be *non-rigid* (Fine 1995). A property $\lambda x.P(x)$ is *rigid* iff it abbreviates a conjunction of identities $x = a_1 \vee \ldots \vee x = a_\alpha$, where α is some ordinal. Fine (1995) shows that some dependencies can exploit rigid properties. For instance, suppose that only Jane and Mary are on the wall and define $\lambda x.$on the wall$(x) = \lambda x.x = \mathrm{Jane} \vee x = \mathrm{Mary}$. Suppose also that John spoke to Jane and Mary when they were on the wall and that the connection is strictly accidental: the fact that the girls were on the wall has nothing to do with the fact that John spoke to them. Observe then that we have the following dependency in Fine's (1995) system:

$\Box_{\lambda x.\text{on the wall}(x)\vee\lambda x.\text{John spoke to}(x)}\forall x(\text{on the wall}(x) \Rightarrow \text{John spoke to}(x))$.

While John spoke to Jane and Mary when they were on the wall, there is no substantial connection between the speaking event and the localisation of the girls. *Any* is odd in such cases.

(12) John spoke to *any/every person who was on the wall

Generally speaking, *any* is odd when the N-property is rigid (in Fine's sense). Conversely, for *any* to be admissible, the N-domain must be allowed to vary. This is not possible for descriptive sentences like (2), which are predictably odd.

Rigidity can be avoided in two ways. First, the N domain can be variable: this simulates the (much stronger) property of obligatory variation in relevance logics (Fine 1988). By and large, having variation on a property forbids any situation in which its dependency profile comes, not from the property itself, but from the identity of the individuals which (happen to) satisfy it. Second, there might be simply no P-event associated to any member of N in a dependency of form $\Box_{\mathrm{N}\,\vee P}\phi$. This accounts for the PS behaviour of *any*: *any* fits naturally into negative or downward monotone contexts because it can make them appear as dependency carriers. Consider (7). This sentence says that, in virtue of the nature of Mary's reading(s) and of books, Mary read no book. Since individuals as such do not 'percolate' through an *any*-phrase, a negative clause with *any* does not refer to a definite set of negative events or situations, but rather to the absence of events or situations of a certain type. Non-rigidity is warranted by the fact that the individual books which have not been read do not matter (they cannot be singled out by enumerating particular negative events).

3. *Any* can be interpreted as an existential or universal quantifier, but the chosen interpretation must be compatible with some universally quantified dependency. If *any* is existential, there must be an associated epistemic/affective/deontic information which can be expressed by a universally quantified formula carrying the dependency between the N and another property. If *any* is universal, every universally quantified interpretation associated with the sentence it occurs in must carry a non-rigid dependency. Let us illustrate the two cases. Consider first (9).

The *surprised* version is associated with an epistemic situation, representing the beliefs of the speaker, in which no book has been read by Mary. This a standard case of absence of event/situation of a certain type. The *glad* version either carries no such expectation and is then unable to provide a dependency, if *any* corresponds to a $\exists$, or is blocked by rigidity as in (2), if *any* corresponds to a $\forall$. Consider now a variant of (8).

(13) #At least two students read any book which was on the reading list

On its existential interpretation ($\approx$ 'a book'), this sentence is odd, because it fails to convey any universally quantified information. If *any* corresponds to $\forall$, the sentence is acceptable (for some speakers). Suppose that S is a possible situation where the sentence is true. In S a certain number of students, not less than two, read all the books. The relative clause allows for variation. Even if books remain constant we can imagine that *different* subsets of books constitute the reading list. So we are never confined into a rigid interpretation.

More formally, we capture the behaviour of *any* by the constraint **NI**. We need some terminological conventions first. A *modal constraint* is a constraint on a tuple of possible worlds/situations $(w_0, w_1 \ldots w_n)$, where w_0 is the actual world. A modal configuration is a pair $\langle(w_0, w1 \ldots w_n), \mathcal{C}\rangle$, where $\mathcal{C}$ is a set of constraints on $(w_0, w1 \ldots w_n)$. In a modal configuration, we say that $w_1 \ldots w_n$ are accessible from w_0. When $n = 0$, w_0 is accessible from itself. An expression ψ *associated* with some logical form LF_S of a sentence S whenever it describes a state of affairs in which LF_S is true if S is an assertion, or in which an appropriate answer to LF_S is true, if S is a question, an appropriate execution w.r.t. LF_S is true, if S is a command, an obligation or a permission, etc.

Non individuation, NI Let S be a sentence of form (A) *Any* N VP or (B) NP V *any* N, and let LF(S) be the set of its logical forms, where *any* can be interpreted as $\exists$ or $\forall$. Let ϕ be a member of LF(S). We say that ϕ is an admissible interpretation only if:

a. if *any* is existential, ϕ entails some ψ of form $\forall x(\text{N}(x) \Rightarrow \chi(x))$, if *any* is universal some ψ with the same universal form is associated with ϕ.

b. For every such ψ, there is a modal configuration $\langle(w_0, w1 \ldots w_n), \mathcal{C}\rangle$ where ψ holds and which respects the following constraint. Let N correspond to the conjunction of properties $P_1, \ldots, P_n$. For every world w_j accessible from w_0, each individual i which satisfies a subset $\mathcal{P}$ of $P_1, \ldots, P_n$ in w_0 and every member k w.r.t. ψ of the witness set of VP in (A) or NP in (B), it is not possible to prove that $k(i)$ (for (A)) or $\text{V}(k, i)$ (for (B)) is true in w_j from the fact that $\mathcal{P}(i)$ is true in w_0 and $\mathcal{C}$.

Partially Fixed Reference, PFR A noun N is *descriptively interpreted* in a sentence ϕ(N) if the reference of N is *partially fixed* with respect to ϕ, in the following sense. Let $\mathcal{P} = \{P_1 \ldots P_n\}$ be a set of properties introduced by N. $\mathcal{P}$ has a partially fixed reference in the actual world w_0 if there is a subset $\mathcal{P}'$ of $\mathcal{P}$ such that, if the reference of $\mathcal{P}'$ in w_0 is a set $\mathbf{P}'$ of individuals, ϕ(N) is true in a world w' only when the reference of $\mathcal{P}'$ in w' is the same set $\mathbf{P}'$. In a descriptive sentence or clause, NPs have a partially fixed reference whenever they point to possibly existing objects (books but not unicorns). Their N lexical head has a fixed reference while the modifiers are allowed to denote different sets of individuals whenever they do not describe accidental properties, as in (12).

This definition says that a noun has a partially fixed reference if we are not free to change the set of individuals which satisfy some given subset of the properties designated by the noun across worlds. Descriptive sentences purport to describe the world as it is. So every NP which occurs in them will have a partially fixed reference, unless it clearly designates non–existing objects. The reference of a NP in a descriptive sentence is totally fixed in two cases. When a N is not modified and points to possibly existing objects, its reference is totally fixed, since $\mathcal{P}$ in **PFR** is a singleton. When the N is modified, but the dependency is accidental, as explained above, the reference is fixed (rigid, in Fine's sense).

3.3 Application

We are now going to review the main configurations in the distribution of *any* to demonstrate how **NI** and **PFR** work. We will leave aside examples which have already been discussed (negation).

1. Descriptive sentences like (2) can be assigned the following logical forms: (i) $\exists x(\text{book}(x) \wedge \text{Mary read}(x))$ and (ii) $\forall x(\text{book}(x) \Rightarrow \text{Mary read}(x))$. (i) may not entail any universally quantified formula, so a. of **NI** is not satisfied. (ii) satisfies a. because it is associated with itself, so ψ of **NI** is simply (ii). Since assertions are normally evaluated in the actual world, the modal configuration reduces to the actual world w_0 itself. In w_0, if b is a book we can safely conclude from (ii) that Mary read(b) is true, contrary to what i stated in **NI**,b.

2. When the N is modified, as in (3), the universal form is again the only candidate. **PFR** allows us to create variation. Since the N lexical head has a fixed reference, the sentence denotes a fixed set of books. In contrast, we may allow for different subsets of books on the reading list. Let b be a book. We cannot conclude from the logical form that b has been read, since b might not be on the reading list, whose identity is allowed to vary.

3. The psychologist example is more subtle. At the moment where the task is described to the subject, there is an indeterminacy. Assume then that we have a set of possible actual worlds, $w_0^1 \ldots w_0^m$. Suppose that s is a square shape on the floor in one of these worlds, then, we must conclude that it will be picked up (see below for *must*-obligations). This is not so for examples of type (3), even if we use several actual worlds to represent variation.

4. Questions easily host *any*. Consider *Did Mary read any book?*. It has only the existential interpretation and entails that, for every book b, the speaker does not know whether Mary read it. We can construct a modal configuration in which Mary read no book or only some books. The speakers which interpret universally *Did Mary read any book which was on the reading list*, can receive an (appropriate) answer 'yes'. In this case, Mary read every book from the reading list, but, owing to the modification of N, variation is preserved. If b is a book, we cannot prove that Mary read b.

5. For examples like (8), the existential interpretation entails that, for every book, at most two students read it. This allows us to avoid the offending situation in which every book was read by some student. For instance, if Tina is a member of the witness set of $ATMOST2students$ w. r. t. $\psi = \forall x(book(x) \Rightarrow AT\ MOST\ 2\ students$ read $x)$ and if b is a book, we cannot be sure that Tina read b. The universal interpretation (*via* a modification of the N) leaves room for variation.

6. *May* and *must* modals can also be accommodated in the present framework. *May*-permissions like (5) can host the existential reading, because it entails that every book may be read by Mary. This is of course compatible with a situation in which Mary reads no book or only some of them. The universal reading (with a modification on the N head) is 'Mary may read every book which Q'. This is associated with itself, and we can, again, construct a modal configuration in which Mary read no book or only some of them.

Must–obligations are different. The existential reading is not possible because there is no universally quantified entailment. The universal reading is associated with a situation in which Mary read all books. This is an offending configuration, so the N head has to be modified for the sentence to become acceptable.

7. Imperatives are a combination of the *may* and *must* cases. The existential interpretation entails that any book may be picked, which carries us back to the case of *may*. The universal one is associated with a situation in which the addressee picks all the books. Again, only modification of the N head can make the sentence acceptable.

8. Generics allow variation by nature, since they do not allude to fixed sets of individuals. Accordingly they may host the universal *any*, as in (1), because, from the fact that o is an owl in w_0 and that owls hunt mice, I cannot prove that o hunts mice in another world. Since we are not in a descriptive sentence, variation is allowed even on the N head (i.e. *owl*). So, o might not be an owl in a world different from w_0.

4 Conclusion

Summarising, we propose that *any* draws its homogeneity from the requirement of dependency, which is realized in English as the **NI** constraint. A similar relation with dependency exists in other languages, for instance in French for the two determiners *tout* (a sort of modal *every*, studied in (Tovena & Jayez 1997)) and *n'importe quel* (a sort of purely existential *any*). One may reasonably expect that the dependency requirement will be linguistically implemented in various ways across languages. A related, open, question is whether all free–choice items, which convey a sense of indiscriminacy or *quodlibeticity* (Horn, after Hamilton), are manifestations of a dependency requirement or whether some of them express only the existence a range of possibilities.

References

Carlson G., 1981, Distribution of free-choice *any*. *CLS* 7:8–23

Davison A., 1980, *Any* as universal or existential?. In van der Auwera J.(ed.) *The Semantics of Determiners*. London: Croom Helm

Dayal V., 1995, Licensing *any* in non–negative/non–modal contexts. *SALT V*:72–93

Fine K., 1985, *Reasoning with Arbitrary Objects*. Oxford: Basil Blackwell

Fine K., 1988, Semantics for Quantified Relevance Logics. *Journal of Philosophical Logic* **24**:241–273

Giannakidou A., 1997, *The Landscape of Polarity Items*. Doctoral dissertation, University of Groningen

Horn L.R., 1996, Pick a theory (not just *any*) theory: Indiscriminatives and the free–choice indefinite, talk delivered at the Groningen conference on *Perspectives on Negation*, August 24 1996

Israel M., 1996, Polarity Sensitivity as Lexical Semantics. *Linguistics and Philosophy* **19**:619–666

Kadmon N. and F. Landman, 1993, *Any*. *Linguistics and Philosophy* **16**:353–422.

Kempson R., 1985, More on *any*: Reply to Ladusaw. *NELS* 15:234–255

Ladusaw W.A., 1979, *Polarity Sensitiviy as Inherent Scope Relations*. Ph.D. thesis, University of Texas, Austin

Lee Y.S. and L.R. Horn, 1994, *Any* as Indefinite plus *Even*. Unpublished manuscript, Yale University

Tovena L.M., 1996, *Studies on Polarity Sensitivity*. Ph.D. thesis, University of Edinburgh

Tovena L.M and J. Jayez, 1997, Déterminants et irréférence. L'exemple de *tout*. In J.M. Reichler–Béguelin (ed.) *Référence nominale et temporelle*, Berne:Peter Lang, to appear

Zwarts F., 1995, Nonveridical contexts. *Linguistic Analysis* **25**:286–312

PROXIMITY MODAL LOGICS

Dimiter Vakarelov
Sofia University

Abstract

A modal logic $\mathcal{PML}$ — Proximity Modal Logic, with a binary modality $\Diamond(P,Q)$ with intuitive reading "P is near Q from certain point of view" is introduced. A possible world semantics for $\mathcal{PML}$ is given, which is based on the notion of proximity relation between sets, studied in the theory of proximity spaces [1]. An axiomatization and completeness theorem with respect to several classes of proximity spaces is proved, including one of the best examples: the universe is a pseudo-metric space and "P i s near Q" iff the distance between P and Q is zero. Using filtration it is proved that $\mathcal{PML}$ has fmp with respect to a class of its models, which implies its decidability. In the conclusion, some extensions of $\mathcal{PML}$ are disscussed and an application to the theory of generalized quantifiers is proposed.

Introduction

In the common sense reasoning we often say for a two sentences P and Q that they are near from certain point of view. We treate this connection between sentences as a binary modality $\Diamond(P,Q)$. The main aim of this paper is to find a satisfactory formal semantics and complete axiomatization of this modality. Since in the possible world semantics sentences are identified with sets of possible worlds, a natural way to assign an appropriate meaning of "P is near Q from certain point of view" is to use the topological notion of proximity relation between sets, studied in the theory of proximity spaces [1].

Let X be a non-empty set and δ be a binary relation between subsets of X, δ is called a *proximity on* X and the pair (X,δ) *proximity space*, if it satisfies the axioms (Prox 1), (Prox 2) and some of the axioms (ρ), (σ) and (τ), formulated below ($A,B,C \subseteq X$ and $A\delta B$ to be read as "A near B"):

(Prox 1) $A\delta(B\cup C)$ iff $A\delta B$ or $A\delta C$ and
$(A\cup B)\delta C)$ iff $A\delta C$ or $B\delta C$ (*Distributivity axioms*),
(Prox 2) If $A\delta B$ then $A\neq\emptyset$ and $B\neq\emptyset$ (*Emptyset axiom*),
(ρ) If $A\cap B\neq\emptyset$, then $A\delta B$ (*Reflexivity axiom*),
(σ) If $A\delta B$ then $B\delta A$ (*Simmetry axiom*), and
(τ) If $A\overline{\delta}B$ then there exists $C\subseteq X$ such that $A\overline{\delta}C$ and $(X-C)\overline{\delta}B$ (*Transitivity axiom*)

If all of the axioms are satisfied then δ is called *Efremovič proximity* (EF-proximyty). Čech in [2] studies a proximity relation, known as *Čhech proximitiy (C-proxymity)*, which satisfies all of the above axioms except (τ).

An important example, from which EF-proximity had been extracted by Efremovič, can be defined in a pseudo-metric space (see [2]) (X,d), putting for subsets $A,B\subseteq X$ $A\delta B$ iff the distance between A and B is zero. Such proximity is called *pseudo-metric proximity.*

Another example, called *relational proximity*, can be defined as follows. Let $X\neq\emptyset$ and R be a binary relation in X. For subsets $A,B\subseteq X$ define $A\delta B$ iff $(\exists x\in A)(\exists y\in B)(Rxy)$. Then thus defined δ satisfies the axioms (Prox 1) and (Prox 2). If in addition R is a reflexive (symmetric, transitive) relation then δ satisfies the reflexivity axiom ρ (the symmetry axiom σ, the transitivity axiom τ). Consequently, if R is an equivalence relation, then δ is an EF-proximity, if R is a reflexive and symmetric relation, then δ is a C-proximity. This costruction motivates the names of the axioms (ρ), (σ) and (τ).

The language of our logic — $\mathcal{PML}$ — "Proximity Modal Logic", is an extension of the language of classical propositional logic with one binary modality $\Diamond$ and one unary modality $\blacksquare$, to be interpreted as the universal modality, which will play only a technical role in the axiomatization. So the new formulas are $\Diamond(A, B)$ and $\blacksquare A$. We abbreviate $\Box(A, B) = \neg\Diamond(\neg A, \neg B)$ and $\blacklozenge A = \neg\blacksquare\neg A$.

Semantical structures for $\mathcal{PML}$ are systems of the form (X, Δ), called proximity frames, where X is a non-empty set of possible worlds and Δ is called a proximity distribution — a function assigning to each world $x \in X$ a proximity relation Δ_x in X. In proximity frames each possible world x has its own proximity relation Δ_x and for the subsets A and B $A\Delta_x B$ have the following informal reading "A is near B from the point of view of x".

If Δ_x is an EF-proximity (C-proximity, etc) for all $x \in X$ then (X, Δ) is called *EF-proximity frame* (*C-proximity frame*, etc). If (X, Δ) is a relational proximity frame, then for each $x \in X$ Δ_x will denote also the binary relation which determines the proximity Δ_x. In this case Δ is in fact a ternary relation and (X, Δ) will be considered as a ternary relation structure. Let (X, R) be a ternary relation structure, satisfying some of the following conditions:

(ref) $Raxx$ (reflexivity),
(sym) $Raxy \to Rayx$ (symmetry),
(tr) $Raxy \;\&\; Rayz \to Raxz$ (transitivity).

Then, if (X, R) satisfies (ref) and (sym) it defines in the above sence a C-proximity frame in X, if (X, R) satisfies (ref), (sym) and (tr), then it defines an EF-proximity frame in X.

Now the semantics of $\mathcal{PML}$ is a Kripke style semantics in proximity frames, defined as follows. Let v be a valuation of the propositional variables into a frame (X, Δ) asigning to each variable p a subset $v(p) \subseteq X$. We define the satisfiability relation $x \Vdash_v A$ — "the formula A is true in the world x at the valuation v" inductively as uisual, which for $\Diamond(A, B)$ and the universal modality $\blacksquare$ satisfies the following clauses:

$x \Vdash_v \Diamond(P, Q)$ iff $\{y \in X : y \Vdash_v P\}\Delta_x\{y \in X : y \Vdash_v Q\}$
$x \Vdash_v \blacksquare P$ iff $(\forall y \in X) y \Vdash_v P$

Informally, P is near Q at the world x, if the sets of the worlds in which P and Q are true are near from the point of view of x.

If the interpretation is given in relational proximity frame (X, Δ) then the above semantics for $\Diamond(P, Q)$ can be rewrite as a ternary relation semantics as follows:

$x \Vdash_v \Diamond(A, B)$ iff $(\exists y, z \in X)(\Delta_x yz \;\&\; y \Vdash_v A \;\&\; z \Vdash_v B)$.

We present the following axiomatization of $\mathcal{PML}$.

Axioms and rules for $\mathcal{PML}$

All Boolean tautologies
$\Box(P \Rightarrow Q, R) \Rightarrow (\Box(P, R) \Rightarrow \Box(Q, R))$,
$\Box(P, Q \Rightarrow R) \Rightarrow (\Box(P, Q) \Rightarrow \Box(P, R))$,
$\blacksquare(P \Rightarrow Q) \Rightarrow (\blacksquare P \Rightarrow \blacksquare Q)$, $\blacksquare P \Rightarrow P$,
$\blacksquare P \Rightarrow \blacksquare\blacksquare P$, $\blacklozenge\blacksquare P \Rightarrow P$, $\Diamond(P, Q) \Rightarrow \blacklozenge P \wedge \blacklozenge Q$,
$\Diamond(P, Q) \Rightarrow \Diamond(Q, P)$, $\blacklozenge(P \wedge Q) \Rightarrow \Diamond(P, Q)$.
(MP) $\frac{A, A \Rightarrow B}{B}$, (Nor) $\frac{A}{\blacksquare A}$

The main aim of this paper is the following

Completeness Theorem for $\mathcal{PML}$. *$\mathcal{PML}$ is sound and complete in the class of all proximity frames and in the class of all pseudo-metric proximity frames.*

The proof, which will be given in the next section, goes as follows. First, using canonical model construction, we prove that $\mathcal{PML}$ is complete in the class of all relational C-proximity frames, considered as ternary ralation structures. Then using filtration we obtain a completeness of $\mathcal{PML}$ with respect to the class of finite relational C-proximity frames. In the next step we prove that each finite relational C-proximity frame is a p-morphic image of a denumerable relational EF-proximity frame. The proof here is by a generalization of the Sahlkwist's [3] unraveling construction, applied to ternary relation semantics. Then, finaly, we show that each denumerable relational EF-proximity frame is a pseudo-metric proximity frame, which ends the proof of the completeness theorem. As a corollary of the filtration step we obtain that $\mathcal{PML}$ is decidable.

In the Conclusion we disscuss an extension of $\mathcal{PML}$, complete in the class of EF-proximity frames with constant distribution and a connection of this extension with a kind of generalized binary quantifier $(\mathbf{PROX}\ xy)(P(x), Q(y))$ with similar semantics.

1 Completeness theorems for $\mathcal{PML}$

The following statement is a completeness theorem for $\mathcal{PML}$ with respect to C-proximity frames.

Proposition 1.1 *The following conditions are equivalent for any formula A of $\mathcal{PML}$:*

(i) A is a theorem of $\mathcal{PML}$,
(ii) A is true in the class of C-proximity frames,
(iii) A is true in the class of relational C-proximity frames,
(iv) A is true in the class of finite relational C-proximity frames.

Proof. The implications $(i) \to (ii) \to (iii) \to (iv)$ state soundness.

The implication $(iii) \to (i)$ is proved by using generated canonical models for polyadic modalities (see [4]). Namely, let X be the set of all maximal consistent sets of $\mathcal{PML}$ and define the following binary relations in X:

$R_x yz$ iff $(\forall AB)(A \in y \;\&\; B \in z \to \Diamond(A, B) \in x)$.
Syz iff $(\forall A)(\blacksquare A \in y \to A \in z)$.

Since $\blacksquare$ is an S5 modality, then S is an equivalence relation. Let $a \in X$ and $S(a)$ be the equivalence class determined by a. Using the axioms of $\mathcal{PML}$ one can prove that $(S(a), R)$ is a ternary frame satisfying the conditions (ref) and (sym). So for each $a \in X$the pair $(S(a), R)$ is a C-proximity frame, called generated canonical frame for $\mathcal{PML}$. Now by a standard argument one can prove that each non-theorem A can befalsified in some generated canonical frame $(S(a), R)$ for $\mathcal{PML}$.

The implication $(iv) \to (iii)$ can be obtained by the method of filtration, applying the minimal filtration to the ternary relation semantics. $\dashv$

Corollary 1.2 *$\mathcal{PML}$ is decidable.*

In order to prove the completeness of $\mathcal{PML}$ with respect to EF-proximity frames we will show that each relational C-proximity frame, considered as a ternary relation frame, is a p-morphic image of a relational EF-proximity frame. To this end we will generalize the Sahlkvist's unraveling construction for the case of termary relation semantics.

The unraveling construction

Let (X, R) be a relational system and R be a ternary relation on X. For $a \in X$ we define the the notion of finite $a - R$-sequence. This is any finite sequence $\alpha =< x_0, \dots, x_n >$ such that $x_0 = a_0 = a$ and for any $k \geq 0$ $x_{3k} = a_k \in X$,

$x_{3k+1} = (b_k, (a_k, b_k, c_k))$, $x_{3k+2} = (c_k, (a_k, b_k, c_k))$, where $(a_k, b_k, c_k) \in R$ and either $a_k = b_{k-1}$ or $a_k = c_{k-1}$.

Let X_a be the set of all $a - R$–sequences in X. X_a will be called a ternary tree over X determined by R with a root a. Define a ternary relation ρ in X_a as follws: for $\alpha, \beta, \gamma \in X_a$ $\rho(\alpha, \beta, \gamma)$ is true only in the following three cases:

Case 1: $\alpha =< x_0, \dots, x_{3k} >$, $\beta =< \alpha, x_{3k+1} >$, $\gamma =< \beta, x_{3k+2} >$ and in this case $a_k = c_{k-1}$.

Case 2: $\alpha =< x_0, \dots, x_{3k+1} >$, $\beta =< \alpha, x_{3k+2} >$, $\gamma =< \beta, x_{3k+3} >$ and in this case $a_{k+1} = b_k$.

Case 3: $\alpha =< x_0, \dots, x_{3k+2} >$, $\beta =< \alpha, x_{3k+3} >$, $\gamma =< \beta, x_{3k+4} >$ and in this case $a_{k+1} = c_k$.

Lemma 1.3 *(i)* $\rho(\alpha, \beta, \gamma)$ & $\rho(\alpha, \delta, \gamma) \rightarrow \beta = \delta$,
(ii) $\rho(\alpha, \beta, \gamma)$ & $\rho(\alpha, \beta, \delta) \rightarrow \gamma = \delta$,
(iii) $\rho(\alpha, \beta, \gamma) \rightarrow \overline{\rho}(\alpha, \gamma, \delta)$.

Define in X_a a relation R_a as follows:
$R_a(\alpha, \beta, \gamma)$ iff $\beta = \gamma$ or $\rho(\alpha, \beta, \gamma)$ or $\rho(\alpha, \gamma, \beta)$
For $\alpha \in X_a$ define $f(\alpha)$ as follows:

- If the last element of α is in the form $x_{3k} = a_k$, put $f(\alpha) = a_k$,
- If the last element of α is in the form $x_{3k+1} = (b_k, (a_k, b_k, c_k))$, put $f(\alpha) = b_k$,
- If the last element of α is in the form $x_{3k+2} = (c_k, (a_k, b_k, c_k))$, put $f(\alpha) = c_k$.

Lemma 1.4 (The Unraveling Lemma)
The system (X_a, R_a) is a ternary relation structure satisfying (ref), (sym) and (tr) and hence can be considered as a relational EF-proximity frame.

(ii) Let (X, Δ) be a relational C-proximity frame and consider Δ as a ternary relation on X. Let X_a be a ternary tree with a root a determined by Δ. Then f is a p-morphism from the relational EF-proximity frame (X_a, R_a) into (X, Δ).

Proof. Use lemma 1.3 and the corresponding definitions. ⊣

Let us note that if we start with a finite relational C-proximity frame (X, Δ) then for each $a \in X$ the relational EF-proximity frame (X_a, R_a) is denumerable.

We need also the following proposition.

Proposition 1.5 *If a relational EF-proximity space is denumerable then it is determined by a pseudo-metric.*

Proof. Let X be a denumerable set, R be an equivalence relation in X and δ be the relational EF-proximity determined by R. Let $A_1, A_2, \dots$ be an enumeration of the equivalence classes of X. Let for $x \in X$ $N(x)$ be the number i of the unique class A_i containing x. Define $d(x, y) = |N(x) - N(y)|$. It is easy to see that d is a pseudo-metric which determines the proximity δ. ⊣

Now we a ready to formulate the main theorem of the paper.

Theorem 1.6 The Main Completeness Theorem for PML. *The following conditions are equivalent for any formula A of $\mathcal{PML}$:*
(i) A is a theorem of $\mathcal{PML}$,
(ii) A is true in all EF-proximity frames,
(iii) A is true in all pseudo-metric proximity frames.

Proof. The implications $(i) \rightarrow (ii) \rightarrow (iii)$ are obvious. To prove $(iii) \rightarrow (i)$ suppose that A is not a theorem of $\mathcal{PML}$. By 1.1 A is falsified at some point a in a finite C-proximity frame (X, Δ). Then applying the unraveling construction we obtain a denumerable proximity frame $F = (X_a, R_a)$. By the Unraveling Lemma 1.4 A is falsified in F and by 1.5 F is a pseudo-metric proximity frame. ⊣

2 Conclusions

We have proved that $\mathcal{PML}$ is complete both in the class of C-proximity frames and in the class of EF-proximity frames. This shows that the language of $\mathcal{PML}$ is too weak to distinguish these two classes of frames. It follows from here that the condition (tr) — transitivity for ternary relation frames, is not modaly definable. If we extend the language, for instance with difference modality [5], then there is a formula, which defines (tr) and separates the logic of C-proximity frames from the logic of EF-proximity frames.

One reasonable extension of $\mathcal{PML}$ is the logic of all EF-proximity frames with constant proximity distribution — $\mathcal{PML}^{cd}$. Then the proximity frame is simply an EF-proximity space (X, δ) and the semantics of $\Diamond(P, Q)$ is just the following one:

$x \Vdash_{\overline{v}} \Diamond(P, Q)$ iff $\{y : y \Vdash_{\overline{v}} P\}\delta\{y : y \Vdash_{\overline{v}} Q\}$.

An axiomatization of $\mathcal{PMLC}^{cd}$ can be obtained by adding to the axioms of $\mathcal{PML}$ the following formulas

$\Box(P, Q) \Rightarrow \Box(\Box(P, Q), R)$,

$\neg\Box(P, Q) \Rightarrow \Box(\neg\Box(P, Q), R)$.

One interesting class of EF-proximity spaces are those satisfying the condition of separativity:

(Sep) For every two points $x, y \in X$, if $\{x\}\delta\{y\}$ then $x = y$.

Examples of separative EF-proximity spaces can be constructed by metric spaces (see [1], [2]): $A\delta B$ iff $d(A, B) = 0$.

Problem 2.1 *Find axiomatizations of the proximity logics complete respectively in the following classes of proximity frames:*

(i) all separative EF-proximity frames,

(ii) all metric proximity frames,

(iii) all separative EF-proximity frames with constant distribution,

(iv) all metric proximity frames with constant distribution.

Let us note that separative relational EF-spaces are trivial (called also "discrete"): $A\delta B$ iff $A \cap B \neq \emptyset$. Consequently neither of the above logics is complete in a ternary relation semantics. This shows that one can not follow the completeness proof of $\mathcal{PML}$. Another interesting fact for the logic of separative EF-proximity frames is that it do not possess finite model property with respect to its standard semantics. This is because all finite separative EF-spaces are "discrete".

The logic $\mathcal{PML}^{cd}$ is a propositional counterpart of the following first-order logic with generalized binary quantifier, to be denoted here by **PROX**. The semantics of **PROX** is similar to that of $\Diamond(P, Q)$ in EF-proximity spaces. The syntax of **PROX** is: for any two first-order formulas P, Q and individual variables x, y, the following is a first-order formula — $(\mathbf{PROX}\ x, y)(P, Q)$. The interpretations of this language are in structures (X, δ, m), where (X, δ) is an EF-proximity space (or any other kind of proximity space) and m is a meaning function assigning standard meaning to functional and predicate symbols. By a valuation we mean any mapping v from individual variables into X. Then v is extended in a standard way by induction to arbitrary terms and formulas, where for a term t $v(t)$ is an element of X and for a formula P $v(P)$ is true=1 or false=0. We will spell out only the definitions for quantifiers. To this end we need the following notation: for a valuation v, individual variable x and $a \in X$ v^x_a is a new valuation defined as follows:

$$v^x_a(y) = \begin{cases} a & if \quad x = y \\ v(y) & if \quad x \neq y \end{cases}$$

Using this notation the semantics of $\exists$ and **PROX** is the following

- $v((\exists x)P) = 1$ iff $\{a \in X : v^x_a(P) = 1\} \neq \emptyset$,
- $v((\mathbf{PROX}\ x, y)(P, Q)) = 1$ iff $\{a \in X : v^x_a(P) = 1\}\delta\{a \in X : v^y_a(Q) = 1\}$.

Let us note that in this logic the usual quantifiers are expressible by **PROX**:

$(\exists x)P \Leftrightarrow (\mathbf{PROX}\ x, x)(P, P)$.

The following frormulas are examples of "proximity" tautologies:

$(\exists x)(P \wedge Q) \Rightarrow (\mathbf{PROX}\ x, x)(P, Q)$,
$(\mathbf{PROX}\ x, y)(P, Q) \Rightarrow (\mathbf{PROX}\ y, x)(Q, P)$,
$(\mathbf{PROX}\ x, y)(P \vee Q, R) \Leftrightarrow (\mathbf{PROX}\ x, y)(P, R) \vee (\mathbf{PROX}\ x, y)(Q, R)$.

We end with a formulation of the following

Problem 2.2 *Find axiomatizations of first-order logic with* **PROX** *complete respectively in the following classes of interpretations:*
(i) all C-proximity spaces,
(ii) all EF-proximity spaces,
(iii) all pseudo-metric proximity spaces,
(iv) all metric proximity spaces.

References

[1] Naimpally S. A. and B. D. Warrack, *Proximity Spaces*, Cambridge University Press, 1970.

[2] Čech, E., *Topological Spaces.* Academia, Publishing house of the Czechoslovak Academy of Sciences, Prague, 1966.

[3] Sahlqvist, H. "Completeness and correspondence in the first and second order semantics for modal logic". In S. Kanger ed. *Proc. of the Third Scandinavian Logic Symposium, Uppsala 1973*, North-Holland, Amsterdam, 1975, pp 110-143.

[4] Vakarelov, D. "Rough polyadic modal logics", Journal of Applied Non-Classical Logics, vol 1, 1(1991), 9–35.

[5] Venema Y. many-dimensional Modal Logics. PhD thesis, Institute for Logic, Language and Computation, Universiteit van Amsterdam, 1991.

Presuppositions among friends; extended abstract

Kees Vermeulen[1] & Heleen Hoekstra, UiL OTS, Utrecht University

Introduction It is widely acknowledged nowadays that a proper model of discourse processing should reckon with a range of phenomena that were traditionally relegated to the domain of pragmatics. This constitutes a major challenge for the formal semantics of discourse. In this paper, we look at two such phenomena: the multi-agent character of discourse and the strategic decisions of the agents involved. In particular we consider their role in presupposition handling.
The role of a presupposition is not just a matter of truth conditions. In dynamic semantics, an additional tool for presupposition analysis is the concept of a *precondition* for processing: before an expression can be processed, its preconditions/presuppositions have to be checked. This approach is *hearer* oriented: it explains how someone who hears a sentence with a presupposition behaves. We will see that an analysis of presuppositions in discourse should include a description of their role for *all* agents, not only as a hearer, but also as a speaker.
Furthermore, the 'precondition view' corresponds to just one strategy a hearer might have: objecting in case of presupposition failure. However, she can also choose to accommodate (or even ignore the presupposition). The notion of a *discourse strategy* for a certain discourse situation suggests itself.
In this paper, we go some way towards formalising a multi-agent analysis that allows for different strategies for presupposition handling. The formal model is limited: it makes use of a simple representation language, allows for only a few varieties of discourse strategies, and only includes two agents. Even this first formalisation already is revealing: in an example we show how the formal model brings out the relevant distinctions.

Some examples Consider the following discourses between participants 1 and 2 (the index indicates who is the speaker):

(i) 1: I've decided to go to Sarah's party after all.
2: But she's fallen ill, so the whole thing has been cancelled.
1: That doesn't surprise me: she had a nasty cough when I saw her last Wednesday.

(ii) 1: I've decided to go to Sarah's party after all.
2: When will it be? I wasn't invited, so I didn't know about it.
1: That's odd. I've just spoken to her, and she asked if you would come.
2: Oh, that bloody answering machine, I could just as well throw it away!

Discourse (i) starts from the presupposition that there exists such a thing as Sarah's party, a presupposition that is not shared by 2. In fact, 2 understands that 1's information state is not up-to-date as far as the party is concerned, so she objects. From 1's reaction we can infer that he takes 2's view to be the right one, because it is consistent with his own impression of Sarah's physical condition, and that he has updated his information state accordingly.
Discourse (ii) also starts from a presupposition that is not shared by 2, but in this case, she accommodates. What 1 says as a reaction to 2's assertion that she wasn't invited, shows that this is not consistent with his own information, and his reluctance to accept it is subsequently warranted by 2's exclamation about her answering machine.

[1]This author was sponsored by the Foundation of Language, Speech and Logic (TSL) of the Netherlands Organisation for Scientific Research (NWO).

The examples illustrate two things: (a) whether a discourse participant accommodates or not is a strategic decision, and (b) the information states of the participants influence each other throughout the discourse. In the following, we discuss these two phenomena in more detail.

Discourse strategies In different situations, different strategies for presupposition handling make sense. When the speaker is an expert on the discourse topic, a hearer probably accommodates the presuppositions, but in other cases she should object in case of presupposition failure. Expertise is but one factor that determines a hearer's willingness to accommodate presuppositions. A more general factor is *reliability* of discourse participants. In sum, a hearer can choose between accommodating and not accommodating. Similarly, a speaker can choose to say only things she believes (is willing to commit herself to) or otherwise.[2]
The notion of discourse strategy is closely linked to the definition of *success* of what we will call an 'informational discourse'. What counts as a successful informational discourse in its turn depends on what *purpose* the discourse serves. In a class room situation, for instance, the purpose of the discourse, given the pair of initial information states $\langle I_1, I_2\rangle$ (where I_1 and I_2 are the information states of the teacher and the student, respectively), can be informally described as the pair $\langle I_1, I_2 \cap I_1\rangle$. In an examination situation, it will be something like $\langle I_1 \cap KI_2, I_2\rangle$ (where KI_2 stands for 'knows what I_2 looks like'). And in an informational discourse among friends, which aims at information exchange, it will be the pair $\langle I_1 \cap I_2, I_2 \cap I_1\rangle$.
Let us elaborate a bit on the strategic options available to the participants in an informational discourse among friends. Suppose the presupposition of an utterance is not shared by the hearer. Whether she will accommodate or not, does not solely depend on the expertise or reliability she ascribes to the speaker, but also on the *consistency* of the content of the presupposition with what she already knows , as we saw in the examples (i)-(ii). These examples also show that the same holds for the assertion, mutatis mutandis: an assertion will only be accepted right away if its content is compatible with what the hearer already knows.[3] We can easily see why this is so: the aim of a friendly informational discourse is to arrive at the situation $\langle I_1 \cap I_2, I_1 \cap I_2\rangle$, which only makes sense if I_1 and I_2 are consistent with each other. An analysis of discourse processing should include an account of such strategic options.

Multi-agent In 'real' discourse (not a monologue, that is), the information state of a participant gets influenced by those of her fellow participants. Therefore, it is not adequate to model a dialogue as a set of monologues. We can see this in the following discourse between agents 1 and 2 (again, the index indicates which agent is the speaker):

(iii) 1: Jill is pregnant. 2: Sue is pregnant, too.
1: That means there will be three new babies by Thanksgiving.

This example shows how the presuppositions and assertions of consecutive sentences interact: the assertion of one sentence can become the presupposition of the next. In this way, an accommodating agent who has processed the information of her discourse partner can afford to say more in the later stages of a discourse than she

[2] Compare this with the notion of 'licensing' from [GSV97]. It seems that the licensing requirement corresponds to just *one* strategy agents may have.

[3] That assertions, too, play a role in discourse strategy can also be illustrated by another type of informational discourse: in an exam situation, the examiner will not accept new information, either asserted or presupposed. Note that this does not mean that the distinction between presupposition and assertion disappears!

could say at first. Similarly, the ability of a non-accommodating agent to interpret sentences increases as discourse proceeds.
The interaction between speaker and hearer can have other effects as well. For instance, if an agent lies, this lie could bounce back, also with an accommodating discourse partner. Suppose, for instance, that the first sentence of (iii) is uttered by 1 in a clumsy attempt to find out how 2 (her partner) feels about babies, and that, to her knowledge, Jill is in fact not pregnant. The "too" in 2's reaction will now result in presupposition failure.
We can only account for such interaction mechanisms in a model that includes both agents, both as a hearer and as a speaker.

Multi-dimensional discourse models Next we present a formal modal in which both the multi-agent aspect and strategic options of an agent are represented. In the model there will be two agents and two roles: hearer and speaker. In both roles the agent will have a choice of two strategies. This gives sixteen different strategic situations. We will say something about all sixteen situations later on, but first we reduce the complexity: we fix the roles of the agents.

Fixed roles This gives four strategic situations, indicated as (+/– c, +/– a), c for 'committed' and a for 'accommodating'. Discourses are represented in a simple, propositional language $\mathcal{L}$, defined over a set of proposition letters PROP:

DEFINITION 1 ($\mathcal{L}$) $\phi ::= \bot \mid p \mid \phi \wedge \phi \mid (\phi \Rightarrow \phi) \quad (p \in \text{PROP})$

We will interpret the discourses in $\mathcal{L}$ as update functions. But we start off with a basic interpretation function $[\![.]\!]$ that assigns to each formula $\phi \in \mathcal{L}$ a pair $\langle a'_\phi, a_\phi \rangle$. Here a'_ϕ is the information presupposed in ϕ and a_ϕ is the assertion of ϕ. Both presupposition and assertion are sets of possible worlds.

DEFINITION 2 ($[\![.]\!]$) For propositions letters $p \in$ PROP pairs $\langle a'_p, a_p \rangle$ are given such that $a_p \subseteq a'_p \subseteq W$. We set: $[\![\bot]\!] = \langle W, \emptyset \rangle$. $[\![.]\!]$ is extended to complex formulas as follows:[4]

$$[\![\phi \wedge \psi]\!] = \langle a'_\phi \cap (a'_\psi \cup \neg a_\phi),\ a_\phi \cap a_\psi \rangle$$
$$[\![(\phi \Rightarrow \psi]\!] = \langle a'_\phi \cap (a'_\psi \cup \neg a_\phi),\ \neg a_\phi \cup a_\psi \rangle$$

In the next step we use the basic interpretations $[\![\phi]\!]$ to define update functions $\Upsilon_{[\![\phi]\!]}$. Update functions show how the information states of the agents change during the interpretation of discourse. Here information states will just be sets of possible worlds, the worlds that are compatible with the information of the agent. We have two agents, so we get two-dimensional discourse situations: $\langle I', I \rangle$ with $I', I \subseteq W$, where I' is the hearer state and I the speaker state. We define the following update functions on discourse situations:

DEFINITION 3 ($\Upsilon_{\langle a', a \rangle}$)
$\langle I', I \rangle \Upsilon_{\langle a', a \rangle} = \langle I' \cap a, I \rangle$ provided the strategic conditions are fulfilled
$\langle I', I \rangle \Upsilon_{\langle a', a \rangle}$ is undefined otherwise

We get the update functions for formulas $\phi \in \mathcal{L}$ by taking $\Upsilon_{[\![\phi]\!]}$. Interpretation proceeds in a discourse situation provided 'the strategic conditions' are fulfilled. A

[4]This definition is derived systematically in [VV97] and agrees with [KP79] and [Eij94] on the simple language considered here. We refer to those papers for more discussion. Here we point out two features: (i) for basic propositions, we assume that their assertion is more informative than their presupposition: $a_p \subseteq a'_p$. By the above definition of $[\![.]\!]$ this property is inherited by complex formulas ϕ. (ii) the definition ensures that presuppositions of later parts of an utterance are weighed against the information provided by the earlier parts of the utterance.

committed speaker ($+c$) will check the asserted information with her current information state: $I \subseteq a_\phi$. And a non-accommodating hearer will check the presupposed information with her information state: $I' \subseteq a'_\phi$. So the conditions for the strategic situation $(+c, -a)$ are: $I \subseteq a_\phi$, $I' \subseteq a'_\phi$. All four strategic situations give rise to their own strategic conditions in this way.[5]

The definition of $\Upsilon_{[\![\phi]\!]}$ mixes techniques from update semantics with the definition of the basic interpretations. We have to check that this mix works. In other words, we need:

PROPOSITION 1 $\Upsilon_{[\![\phi \wedge \psi]\!]} = \Upsilon_{[\![\phi]\!]} \circ \Upsilon_{[\![\psi]\!]}$ for all strategic situations. □

On inputs $\langle I', I \rangle$ where both $\Upsilon_{[\![\phi \wedge \psi]\!]}$ and $\Upsilon_{[\![\phi]\!]} \circ \Upsilon_{[\![\psi]\!]}$ are defined, we get the required output: $\langle I', I \rangle \Upsilon_{[\![\phi \wedge \psi]\!]} = (\langle I', I \rangle \Upsilon_{[\![\phi]\!]}) \Upsilon_{[\![\psi]\!]} = \langle I' \cap a_\phi \cap a_\psi, I \rangle$. So, we only have to check the propagation of the strategic conditions, a simple exercise in Boolean reasoning that we leave to the reader.

We see that, in the two agent model with fixed roles, the influence of discourse strategies comes out nicely: the strategic conditions determine whether a discourse may proceed or not. In the strategic conditions we see that the information state of the speaker can make the difference between continuation and abortion of a discourse. Still, the speaker state itself never changes: the speaker's information state is a parameter that does not vary as discourse proceeds. This will change later on.

Traditional, hearer oriented models of discourse interpretation can be reconstructed here: simply choose the $(-c, -a)$ option[6] to get the same effect as the hearer models of [KP79], [Eij94] and [VV97].

Role switching Next, we consider two agent discourses in which the discourse roles are not fixed: both agents can be hearer and speaker. For each role we still consider the same two strategic options. This gives rise to sixteen different strategic situations for agents 1 and 2, which we indicate as (+/– c +/– a, +/– c +/– a).

To show how the roles switch, we extend the representation language with indices. We write $(i : \phi)$ to indicate that agent i is the speaker of $\phi \in \mathcal{L}$. Discourses with role switching can then be represented as finite sequences of such expressions where the indices switch appropriately.

DEFINITION 4 ($\mathcal{L}_\delta$) $\Delta ::= \langle\rangle \mid \Delta(i : \phi)$ ($\phi \in \mathcal{L}$, and i is not the last index in Δ)

We will write $\langle\rangle$ for the empty discourse in which nothing is said. This gives the discourse language $\mathcal{L}_\delta$. Now we can define the update functions Υ_Δ for the interpretation of $\mathcal{L}_\delta$. They operate on discourse situations $\langle I_1, I_2 \rangle$ with $I_i \subseteq W$ the information state of agent i.

DEFINITION 5 (Υ_Δ) Set $\langle J_1, J_2 \rangle := \langle I_1, I_2 \rangle \Upsilon_\Delta$.

$\langle I_1, I_2 \rangle \Upsilon_{\langle\rangle} = \langle I_1, I_2 \rangle$

$\langle I_1, I_2 \rangle \Upsilon_{\Delta(1:\phi)} = \langle J_1, J_2 \cap a_\phi \rangle$ provided the strategic conditions hold

$\langle I_1, I_2 \rangle \Upsilon_{\Delta(2:\phi)} = \langle J_1 \cap a_\phi, J_2 \rangle$ provided the strategic conditions hold

Let's see how this works for example (iii) above. We assume the strategic situation ($+c$+a, $+c$+a), the situation that we get in case the agents always update when they are in the hearer mode, and always check their utterances with their current information state when in speaker mode. We can represent (iii)

[5]Note that we have chosen not to include a consistency check here. This is not a principled choice, of course, but a simplification.

[6]By setting the speaker strategy to $-c$ we make sure that the information state of the speaker does not play a role.

as $\Delta_{iii} \equiv (1:j)(2:s)(1:t)$, where $[\![j]\!] = \langle W, J\rangle$, $[\![s]\!] = \langle J, J\cap S\rangle$ and $[\![t]\!] = \langle J\cap S, J\cap S\cap M\rangle$, with $J, S, M \subseteq W$ the sets of worlds where Jill, Sue and Mary are pregnant, respectively. (So we assume, for convenience, that Mary is the only other woman who could possibly be pregnant.)
Starting with situation $\langle I_1, I_2\rangle$, discourse Δ_{iii} can lead to a new discourse situation: $\langle I_1\cap S,\ I_2\cap J\cap M\rangle$. But the processing of Δ_{iii} only proceeds if *throughout* the event all the strategic conditions are fulfilled. This will happen if: $I_1 \subseteq J\cap M$ and $I_2 \subseteq S$.
This shows that the conditions for continuation or abortion of a discourse do not just depend on what an agent says in that discourse: from what agent 1 says, we could never predict that she does *not* have to know that S holds. It is not enough either to look at what the agents hear: from what agent 1 hears, it does not show that she needs to know M.
General necessary and sufficient conditions for the continuation of a discourse can be given for each of the sixteen strategic situations. Consider a (finite) discourse $\Delta \equiv (1:\phi_1)(2:\psi_1)(1:\phi_2)(2:\psi_2)(1:\phi_3)\ldots$ in $\mathcal{L}_\delta$. We introduce the following notation:

$$\begin{aligned}
\Gamma_{1:(+c+a)} &:= \textstyle\bigcap_n(a_{\phi_n} \cup \bigcup_{i<n}(\neg a_{\psi_i}))\\
\Gamma_{1:(-c-a)} &:= \textstyle\bigcap_n(a'_{\psi_n} \cup \bigcup_{i<n}(\neg a_{\psi_i}))\\
\Gamma_{1:(+c-a)} &:= \Gamma_{1:(+c+a)} \cap \Gamma_{1:(+c-a)}\\
\Gamma_{1:(-c+a)} &:= W
\end{aligned}$$

In $\Gamma_{1:(\sigma)}$ we add up the strategic conditions that agent 1 will meet at each point in Δ. Conditions $\Gamma_{2:(\sigma)}$ for agent 2 are obtained similarly. In particular: $\Gamma_{2:(+c+a)} := \bigcap_n(a_{\psi_n} \cup \bigcup_{i\leq n}(\neg a_{\phi_i}))$ and $\Gamma_{2:(-c-a)} := \bigcap_n(a'_{\phi_n} \cup \bigcup_{i<n}(\neg a_{\phi_i}))$. Now we get the following result:

PROPOSITION 2 Let a discourse situation $\langle I_1, I_2\rangle$ and a strategic situation (σ_1, σ_2) be given. Then the interpretation of Δ will continue iff $I_1 \subseteq \Gamma_{1:(\sigma)}$ and $I_2 \subseteq \Gamma_{2:(\sigma)}$.

PROOF: We derive $\Gamma_{1:(+c+a)}$. The other conditions are derived analogously.
In case agent 1 follows strategy $\sigma = (+c+a)$, she will always check the ϕ_i with her current information state. This means that she will first check $I_1 \subseteq a_{\phi_1}$, then $I_1 \cap a_{\psi_1} \subseteq a_{\phi_2}$, then $I_1 \cap a_{\psi_1} \cap a_{\psi_2} \subseteq a_{\phi_3}$, etc. This is equivalent to first checking $I_1 \subseteq a_{\phi_1}$, then $I_1 \subseteq a_{\phi_2} \cup \neg a_{\psi_1}$, then $I_1 \subseteq a_{\phi_2} \cup \neg a_{\psi_1} \cup \neg a_{\psi_2}$, etc. The discourse is aborted as soon as one of these checks fails. So, we need the conjunction of these 'checks', which is exactly what $\Gamma_{1:(+c+a)}$ gives us. □

From the proposition we see that the conditions for continuation can involve for each agent a combination of what she says and what she hears. Hence, for an analysis of strategic multi-agent discourse, a multi-dimensional model provides the most natural setting.
Proposition 2 gives the general conditions for the continuation of discourse for all sixteen strategic situations, which makes it possible to compare strategies with respect to 'abortion' behaviour. This establishes a link with game theory (cf. [LR57]): for each initial discourse situation $\langle I_1, I_2\rangle$ the ordering will induce a *pre-order* on the strategic situations. Hence we obtain *utility functions* and a two person discourse becomes an example of a two person game in the technical sense!

Further work We have indicated how to make sense of two important types of pragmatic considerations about the role of presuppositions in discourse. We suspect that many notions from pragmatics can be made formally precise in models of the above kind. We also want to pursue the link with *game theory*. Game theory describes how agents can use strategies to optimise the chances of reaching their goals. Models of the kind we have developed here make it possible to regard n-agent discourses as games between n persons that try to realise a *discourse goal.* This will make available a considerable body of techniques for the formal analysis of discourse.

References

[Bea97] D. Beaver. Presupposition. In J. van Benthem and A. ter Meulen, editors, *Handbook of Logic and Language*, pages 939–1008. Elsevier, 1997.

[Eij94] J. van Eijck. Presupposition failure – a comedy of errors. *Aspects of Computing*, 6A:766–787, 1994.

[Gri75] H. Grice. Logic and conversation. In *Syntax and Semantics (3): Speech Acts*, pages 41–58. Academic Press, 1975.

[GSV97] J. Groenendijk, M. Stokhof, and F. Veltman. Coreference and modality in multi-speaker discourse. In H. Kamp and B. Partee, editors, *Context Dependence in the Analysis of Linguistic Meaning*, Stuttgart IMS, 1997.

[KP79] L. Karttunen and S. Peters. Conventional implicature. In Oh C.-K. and D. Dinneen, editors, *Syntax and semantics (11): Presupposition*, pages 1–56. Academic Press, 1979.

[LR57] R. Luce and H. Raiffa. *Games and Decisions*. John Wiley & Sons, 1957.

[Seu85] P. Seuren. *Discourse Semantics*. Blackwell, Oxford, 1985.

[VV97] A. Visser and C. Vermeulen. Algebras for boolean presuppositions. Technical report, Department of Philosophy, Utrecht University, 1997.

Affiliations and Addresses

Samson Abramsky samson@dcs.ed.ac.uk
The University of Edinburgh, Department of Computer Science
James Clerk Maxwell Building
Mayfield Road
Edinburgh EH9 3JZ
United Kongdom

Maria Aloni aloni@philo.uva.nl
University of Amsterdam, ILLC/Department of Philosophy
Nieuwe Doelenstraat 15
1012 CP Amsterdam
The Netherlands

Nicholas Asher nasher@mail.la.utexas.edu
University of Texas at Austin, Department of Philosophy
Austin, TX
U.S.A.

Mario R.F. Benevides mario@wins.uva.nl
University of Amsterdam, ILLC
Plantage Muidergracht 24
1018 TV Amsterdam
The Netherlands

Reinhard Blutner blutner@asg.ag-berlin.mpg.de
Humboldt-Universität, Projektgruppe Strukturelle Grammatik
Jägerstrasse 10/11
D-10117 Berlin
Germany

Virginia Brennan brennavm@ctrvax.vanderbilt.edu
Vanderbilt University, Linguistics Program
Box 1567-B
Vanderbilt University
Nashville, TN 37235
U.S.A.

Ariel Cohen arikc@bgumail.bgu.ac.il
Ben Gurion University of the Negev, Dept. of Foreign Literatures and Linguistics
P.O.Box 653
Beer Sheva 84105
Israel

Kees van Deemter kees.van.deemter@itri.brighton.ac.uk
University of Brighton, Information Technology Research Institute
Lewes Road, Brighton
BN2 4GJ
United Kingdom

Jaap van der Does jvddoes@wins.uva.nl
University of Amsterdam, ILLC : WINS
Plantage Muidergracht 24
NL-1018 TV Amsterdam
The Netherlands

Regine Eckardt regine.eckardt@uni-konstanz.de
Universität Konstanz, FB Sprachwissenschaft
Universitätsstrasse 10
78464 Konstanz
Germany

Markus Egg egg@coli.uni-sb.de
Universität des Saarlandes, Computerlinguistik, FB 8.7
Postfach 15 11 50
D-66041 Saarbruecken
Germany

Jan van Eijck jve@cwi.nl
Amsterdam, CWI
PO Box 94079
1090 GB Amsterdam
The Netherlands

Nomi Erteschik-Shir shir@bgumail.bgu.ac.il
Ben Gurion University of the Negev, Dept. of Foreign Literatures and Linguistics
P.O.Box 653
Beer Sheva 84105
Israel

Tim Fernando fernando@ims.uni-stuttgart.de
Carnegie Mellon University, Department of Philosophy
135 Baker Hall
Pittsburgh, PA 15213
U.S.A.

Tsutomu Fujinami tsutomu@ims.uni-stuttgart.de
Universität Stuttgart, Institut für Maschinelle Sprachverarbeitung
Azenbergstrasse 12
D-70174 Stuttgart
Germany

Dov Gabbay dg@doc.ic.ac.uk
Imperial College of Science, Technology and Medicine, Computing Department
Huxley Building
180 Queen's Gate
London, SW7 2BZ
United Kingdom

Jelle Gerbrandy gerbrand@philo.uva.nl
University of Amsterdam, ILLC/Department of Philosophy
Nieuwe Doelenstraat 15
1012 CP Amsterdam
The Netherlands

Bart Geurts geurts@cl-ki.uni-osnabrueck.de
Universität Osnabrück, FB 7
49069 Osnabrück
Germany

Anastasia Giannakidou giannakidou@philo.uva.nl
University of Amsterdam, ILLC/Department of Philosophy
Nieuwe Doelenstraat 15
1012 CP Amsterdam
The Netherlands

Jonathan Ginzburg msjihad@pluto.mscc.huji.ac.il,ginzburg@cogsci.ed.ac.uk
Hebrew University of Jerusalem, Dept. of English
Mount Scopus
Jerusalem 91905
Israel

Daniel Hardt dan@cst.ku.dk
Copenhagen, Center for Language Technology
Njalsgade 80
DK-2300 Copenhagen S
Denmark

Herman Hendriks Herman.Hendriks@let.ruu.nl
Utrecht University, Utrecht Institute of Linguistics OTS
Trans 10
3512 JK Utrecht
The Netherlands

Petra Hendriks phendrik@ppsw.rug.nl
University of Groningen, Cognitive Science and Engineering
TCW, PPSW
Postbus 716
9700 AS Groningen
The Netherlands

Klaus von Heusinger klaus.heusinger@uni-konstanz.de
Stevenson College, UCSC, Linguistics Research Center
Santa Cruz, CA 95064
U.S.A.

Robin Hirsch R.Hirsch@cs.ucl.ac.uk
University College, Department of Computer Science
Gower Street
London WC1E 6BT
United Kingdom

Wilfrid Hodges w.hodges@qmw.ac.uk
Queen Mary and Westfield College, School of Mathematical Sciences
Mile End Road
London E1 4NS
United Kingdom

Ian Hodkinson imh@doc.ic.ac.uk
Imperial College, Department of Computing
180 Queens Gate
London SW7 2BZ
United Kingdom

Heleen Hoekstra heleen.hoekstra@let.ruu.nl
Utrecht University, UiL-OTS
Trans 10
3512 JK Utrecht
The Netherlands

Martin Honcoop honcoop@rullet.leidenuniv.nl
Leiden University, ATW/HIL
P.O.Box 9515
2300 RA Leiden
The Netherlands

Helen de Hoop dehoop@let.ruu.nl
Utrecht University, Utrecht Institute of Linguistics OTS
Trans 10
3512 JK Utrecht
The Netherlands

Willem-Olaf Huijsen Willem-Olaf.Huijsen@let.ruu.nl
Utrecht University, Utrecht Institute of Linguistics OTS
Trans 10
3512 JK Utrecht
The Netherlands

Gerhard Jäger jaeger@skyline.asg.ag-berlin.mpg.de
University of Pennsylvania, Institute for Research in Cognitive Science
3401 Walnut Street, Suite 400A
Philadelphia, PA 19104-6228
U.S.A.

Theo M.V. Janssen theo@wins.uva.nl
University of Amsterdam, Department of Computer Science
Plantage Muidergracht 24
1018 TV Amsterdam
The Netherlands

Jan Jaspars jaspars@wins.uva.nl
University of Amsterdam, ILLC
Plantage Muidergracht 24
1018 TV Amsterdam
The Netherlands

J. Jayez jayez@silicone.fr
EHESS-CELITH, B.235
54 Boulevard Raspail
Paris
France

Stefan H. Kaufmann kaufmann@csli.stanford.edu
Stanford University, Department of Linguistics
Building 460
Stanford CA 94305
U.S.A.

Ruth Kempson rk@soas.ac.uk
School of Oriental and African Studies, Linguistics Department
Thornhaugh Street
Russell Square
London, WC1H 0XG, U.K.

Rodger Kibble rk8@soas.ac.uk
School of Oriental and African Studies, Linguistics Department
Thornhaugh Street, Russell Square
London, WC1H 0XG
U.K.

Michael Kohlhase kohlhase@coli.uni-sb.de
Universität des Saarlandes, Computerlinguistik, FB 8.7
Postfach 15 11 50
D-66041 Saarbruecken
Germany

Ivana Kruijff-Korbayova gj@ufal.mff.cuni.cz
Charles University, Institute of Formal and Applied Linguistics
Malostranské náměstí 25
CZ-118 00 Prague 1
Czech Republic

Erik Krabbe eric@philos.rug.nl
Groningen University, Department of Philosophy
A-weg 30
9718 CW Groningen
The Netherlands

Emiel Krahmer krahmer@ipo.tue.nl
Eindhoven University of Technology, Center for Research on User-System Interaction
P.O.Box 513
5600 MB Eindhoven
The Netherlands

Geert-Jan M. Kruijff gj@ufal.mff.cuni.cz
Charles University, Institute of Formal and Applied Linguistics
Malostranské náměstí 25
CZ-118 00 Prague 1
Czech Republic

Michiel van Lambalgen michiell@wins.uva.nl
University of Amsterdam, ILLC : WINS
Plantage Muidergracht 24
NL-1018 TV Amsterdam
The Netherlands

Chungmin Lee clee@plaza.snu.ac.kr
Seoul National University, Dept. of Linguistics
Maebong Samsung Apt. #505
Dogok-dong, Kangnam-ku
Seoul 135-271
KOREA

Lutz Marten rk8@soas.ac.uk
School of Oriental and African Studies, Linguistics Department
Thornhaugh Street, Russell Square
London, WC1H 0XG
U.K.

Alice ter Meulen atm@wins.uva.nl
University of Amsterdam, ILLC
Plantage Muidergracht 24
1018 TV Amsterdam
The Netherlands

Wilfried Meyer Viol wm3@doc.ic.ac.uk
Imperial College, Department of Computing
Huxley Building
180 Queen's Gate
London, SW7 2BZ
United Kingdom

Glyn Morrill morrill@lsi.upc.es
Universitat Politècnica de Catalunya, Dept. de Llenguatges i Sistemes Informàtics
M odul C5 – Campus Nord
Jordi Girona Salgado
1–3 E-08034 Barcelona
Spain

Reinhard Muskens rmuskens@kub.nl
University of Tilburg, Department of Linguistics
2 Warandelaan
5000 LE Tilburg
The Netherlands

Ralf Naumann naumann@phil-fak.uni-duesseldorf.de
Universität Düsseldorf, Seminar für Allgemeine Sprachwissenschaft
Universitätsstrasse 1
40225 Düsseldorf
Germany

Chris Piñón pinon@phil-fak.uni-duesseldorf.de
Universität Düsseldorf, Seminar für Allgemeine Sprachwissenschaft
Universitätsstrasse 1
40225 Düsseldorf
Germany

Paul Piwek piwek@ipo.tue.nl
Eindhoven University of Technology, Center for Research on User-System Interaction
P.O.Box 513
5600 MB Eindhoven
The Netherlands

Massimo Poesio poesio@cogsci.ed.ac.uk
University of Edinburgh, Centre for Cognitive Science / HCRC
2 Buccleuch Place
Edinburgh EH8 9LW
U.K.

Fabien R. Reniers Fabien.Reniers@let.ruu.nl
Utrecht University, UIL-OTS
Trans 10
3512 JK Utrecht
The Netherlands

Maribel Romero romero@linguist.umass.edu
University of Massachussetts at Amherst, Linguistics Department, South College
Amherst, MA 01003
U.S.A.

Robert van Rooy rooy@ims.uni-stuttgart.de
Universität Stuttgart, Institut für Maschinelle Sprachverarbeitung
Azenbergstrasse 12
D-70174 Stuttgart
Germany

Kjell Johan Sæbø k.j.sabo@german.uio.no
University of Oslo, Germanistisk Institutt
Postboks 1004
N-0315 Oslo
Norway

Rob van der Sandt rvdsandt@phil.kun.nl
University of Nijmegen, Department of Philosophy
P.O.Box 9103
6500 HD Nijmegen
The Netherlands

Gabriel Sandu sandu@katk.helsinki.fi
University of Helsinki, Department of Philosophy
P.O.Box 59 (Unioninkatu 38B)
FIN-00014 University of Helsinki
Finland

Hans Smessaert Hans.Smessaert@arts.kuleuven.ac.be
Katholieke Universiteit Leuven, Department of Linguistics
Blijde-Inkomststraat 21
3000 Leuven
Belgium

Harry P. Stein stein@philo.uva.nl
University of Amsterdam, Department of Philosophy
Nieuwe Doelenstraat 15
1012 CP Amsterdam
The Netherlands

Henriëtte de Swart deswart@let.ruu.nl
University of Utrecht, Department of Romance Languages
Kromme Nieuwegracht 29
3512 HD Utrecht
The Netherlands

Anna Szabolcsi annasz@humnet.ucla.edu
UCLA, Department of Linguistics
405 Hilgard Avenue
Los Angeles, CA 90095-1543
U.S.A.

L.M. Tovena tovena@itc.it
Istituto per la Ricerca Scientifica e Tecnologica, ITC
via Sommarive
38050 Povo TRENTO
Italy

Dimiter Vakarelov dvak@fmi.uni-sofia.bg
Sofia University, Department of Mathematical Logic with Laboratory for Applied Logic
Blvd James Bouchier 5
1126 Sofia
Bulgaria

Kees Vermeulen keesv@phil.ruu.nl
Utrecht University, UiL-OTS
Trans 10
3512 JK Utrecht
The Netherlands

Arnis Vilks vilks@microec.hhl.de
University of Leipzig, Leipzig Graduate School of Management
Jahnallee 59
D-04109 Leipzig
Germany

institute *for* logic, language *and* computation