Proceedings of the

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Paul Dekker (ed.)

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Preface

The 1999 edition of the Amsterdam Colloquium is the Twelfth 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) of the University of Amsterdam.

These proceedings contain the abstracts of all papers to be presented at the colloquium. In the first two sections one can find the contributions to the two thematic sessions:

≫ Non Monotonicity and Natural Language
≫ Discourse and Communication. Structured Information Exchange

The third section contains the contributions to the general program. The copyright resides with the individual authors.

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Two place probabilities, beliefs and belief revision: on the foundations of iterative belief kinematics

Horacio Arló-Costa, CMU and Rohit Parikh, CUNY and NYU[1]

Abstract

Making use of van Fraassen's framework for defining beliefs from conditional probabilities, we provide a discussion of the issues and present some new technical results. We provide a complete characterization of countable spaces, show how belief revision can be defined naturally, even by propositions of probability 0, and give some axioms which are satisfied.

1 Introduction

In contemporary work on the foundations of iterated belief change, one strategy appeals to examples, intuition, and symmetry arguments. See, e.g. [3] where the authors modified the foundations of iterated change by (1) focusing on the change of entire epistemic states rather than belief sets, and (2) offering four additional axioms for iterated change.

A different justificatory strategy is to insist on computational feasibility. The main idea here consists in developing feasible algorithms that operate on (possibly finite) conditional knowledge bases, rather than on belief sets or rankings. Judea Pearl and Goldszmidt have developed in [4] an influential approach in this area (the system Z). According to this methodology, when a conditional belief base is updated 'all happens as if' its corresponding ranking gets changed by a method that they call *Bayesian update with hard evidence*. We shall focus on methods recommended by the second strategy. In this extended abstract we construct a probabilistic model for Bayesian update. Therefore we offer further probabilistic justification for a family of methods that have only been investigated so far in terms of their computational efficiency.

2 Technical results

Our model uses two-place probability functions, sometimes called Popper functions in the literature. Bas van Fraassen developed in [8] a probabilistic definition of full belief in terms of such functions.

We offer a modified and extended version of van Fraassen's model of [8] and use it to model Bayesian update. [8] studies two place [probability functions $P(-|-)$ defined on a σ-field F over some set U. The requirements are that
(I) for any fixed A, the function $P(X|A)$ as a function of X is either a (countably additive) probability measure, or has constant value 1.
(II) $P(B \cap C|A) = P(B|A)P(C|B \cap A)$ for all A, B, C in F.

[1]The research of both authors was supported in part by a grant from NSF, and, for Parikh, also by support from the research foundation of CUNY.

The probability (*simpliciter*) of A, $pr(A)$, is $P(A|U)$. We will follow established terminology by referring to (II) as the *Multiplication Axiom*

If $P(X|A)$ is a probability measure as a function of X, then A is *normal* and otherwise *abnormal*. Roughly speaking, a normal set may have measure 0 in which case we do not *expect* to believe it, but we still *might*. E.g. the rationals as a subset of the reals have measure 0, but if we pick a real at random and it turns out to be rational we do not throw up our hands in despair! An abnormal set by contrast is so small that we do not know what to believe if we believe in *that*. Indeed, if A is abnormal, then $P(\emptyset|A) = 1$. Thus A is normal iff $P(\emptyset|A) = 0$. van Fraassen shows in [8] that supersets of normal sets are normal and that subsets of abnormal sets are abnormal. Assuming that the whole space is normal, abnormal sets have measure 0, though the converse need not hold. We now show the following:

Lemma 2.1 *A countable union of abnormal sets is abnormal, though an intersection of normal sets, even a finite intersection, need not be normal.*

Proof 2.1 *The second part is easy. Let X and Y be disjoint normal sets and W an abnormal set. Then since $X \cup W$ and $Y \cup W$ contain the normal sets X, Y respectively, they are both normal. But their intersection is W which is, by assumption not normal.*

Coming to the first part, let us show first that the the union of two abnormal sets X, Y is still abnormal. Note that $P(\emptyset|X \cup Y) = P(\emptyset|X)P(X|X \cup Y)$ from the multiplication axiom. Since X is abnormal, $P(\emptyset|X) = 1$. Thus if $X \cup Y$ were normal, *then $P(\emptyset|X \cup Y) = 0$ and hence $P(X|X \cup Y) = 0$. By a symmetric argument, $P(Y|X \cup Y) = 0$. This is a contradiction since X, Y make up all of $X \cup Y$.*

To come to the countable union case, suppose that $X_i : i \in N$ are countably many abnormal sets and by the argument above, we can suppose that $i < j \rightarrow X_i \subset X_j$. Let $Z = \bigcup X_i$. An argument similar to the one above shows that if Z were normal, *then for all i, $P(X_i|Z) = P(\emptyset|Z) = 0$. But then continuity (a consequence of countable additivity) yields $P(Z|Z) = 0$ which is absurd whether Z is normal or abnormal.* □

In the following we shall confine ourselves to the case where the whole space U is normal. The notion of normality is closely connected to an epistemic analysis of the notion of *a priori*: (A) A is *a priori for* P iff P(A | X) = 1 for all X, iff U - A is abnormal for P.

Slightly modifying vF's definition we define a *core* as a set K which is normal and satisfies the *strong superiority condition* (SSC) i.e. if A is a nonempty subset of K and B is disjoint from K, then $P(B|A \cup B) = 0$ (and so $P(A|A \cup B) = 1$).[2] Thus any non-empty subset of K is more "believable" than any set disjoint from K. It can then be established that all non-empty subsets of a core are normal.

[2] A is *superior to* B whenever P(A | A + B) = 1, where + is symmetric difference.

Lemma 2.2 *(Finesse): all non-empty subsets of K are normal.*

Proof 2.2 *Suppose that K is a core and A a subset of it. Let $B = \emptyset$. Then B is disjoint from K and hence, by SSC, $P(B|A) = P(B|A \cup B) = 0$. Thus A is normal.* □

van Fraassen 's characterization of cores requires a slightly different superiority condition, and the property called (A3) according to which the complement of a core should be normal. There might be arguments in favor of adopting this point of view. For example, if the union of cores represents the strongest proposition *fully* believed by the agent, one might want to preserve the possibility of genuine revisions of this body of belief with normal propositions.[3] Nevertheless, the condition introduces certain asymmetries in the resulting probabilistic models that we prefer to avoid. Also van Fraassen's solution cannot be counted as perfectly parsimounious either. For example, it will entail that if we revise with the largest core (if there is any) such a core cannot be among the cores of the updated function. Further arguments in favor of our reformulation will be offered below.

Formally many of the basic theorems proved by van Fraassen and other scholars who worked in this area can be proved in our modified framework with minor changes. The most salient results will be listed below.

Lemma 2.3 *The family of cores induced by a two place probability function P is nested (van Fraassen, 1995)*

Indeed we have the following important fact:

Theorem 2.1 *(Descending Chains). The chain of belief cores induced by a non-coreless 2-place function P cannot contain an infinitely descending chain of cores.*

We skip the proof as it is already given in (Arló-Costa-1999).

Thus the cores are well ordered under inclusion and closely resemble Grove spheres. Indeed we can show that for any ordinal α there is a space (U, F, P) such that the family of its cores has ordinal α. Let α be any (von Neumann) ordinal. Then $\alpha = \{\beta|\beta < \alpha\}$. For subsets X, Y of α with $X \subseteq Y$ let $P(X|Y)$ equal 1 if $min(X) = min(Y)$ and equal 0 otherwise, i.e. if $min(Y) < min(X)$. Then the cores are precisely the non-zero ordinals $\leq \alpha$, and for the sake of symmetry we include α also as a core.

Lemma 2.4 *There is a smallest as well as a largest core. Moreover, the smallest core has measure 1.*

[3] This might be so even when van Fraassen's account does not give us the tools to perform such a revision. Also according to him the union of cores represents a proposition accepted by the agent rather than its full beliefs.

Proof 2.3 *Since cores are well ordered by inclusion, there is naturally a smallest core. There is also a largest core, namely the union of all cores. To see that this union, say K, is also a core, note first that if X is a nonempty subset of K then there must exist a core K' which overlaps X. Now the subset $X \cap K'$ of K' is normal and thus X is also normal. To see superiority we use a similar argument. Let X, K' be as before and let B be disjoint from K. Then B is also disjoint from K' and hence $X \cap K'$ is superior to B. Hence so is X itself. That the smallest core K_0 has measure one follows from the fact that K_0 is superior to its complement and together they make up measure 1.* □

We propose that the smallest core be identified with (ordinary) beliefs and the largest core with full beliefs, so that in general *full belief* will be distinct from probability 1. Arguments supporting this interpretation are offered in the following section.

3 The countable case

If the set U is countable then very nice properties hold. There is a set of *heavy* points p such that $pr(\{p\}) > 0$ and all of which are normal. There may also be normal (light) points p such that $pr(\{p\}) = 0$. Finally there may be abnormal points p such that $pr(\{p\}) = 0$ and $P(\emptyset|\{p\}) = 1$.

Lemma 3.1 *Let $S = \langle U, F\rangle$ be a countable space and $P(\ -\ |\ -)$ a two-place probability function defined on the space. The set H(P) of heavy points of P constitute the smallest core, which, moreover, has measure 1.*

Proof 3.1 *We already showed that the smallest core has measure 1. Moreover, no heavy point can be dominated, hence the smallest core containes at least the heavy points. Moreover, any set of heavy points is normal, and finally any non-empty set of heavy points is superior to any set of light points, whether normal or abnormal.* □

Let the ordering $<$ on U be defined by $p < q \leftrightarrow P(\{q\}|\{p,q\}) = 0$, i.e. if we know that we have picked one of p, q then it must be p. Similarly, let $p \cong q$ hold iff both $P(\{p\}|\{p,q\})$ and $P(\{q\}|\{p,q\})$ are > 0. Then $<$ is a well quasi-ordering with $\cong$ as its associated equivalence relation and the cores are just sets of normal points closed under $\leq$. The heavy points are all equivalent to each other and in the smallest core. The light normal points are superior to the abnormal points but may have superiority relations among themselves, as the ordinal example above shows.

The fact that (in the countable case) the heavy points constitute the smallest core (which has measure 1), gives support to one of our proposed modifications of van Fraassen's account. In fact, one of the main purposes of the use of two-place functions in the definition of full belief is to avoid a problematic

identification of belief and probability one (which yields the so-called lottery paradoxes - see [6]). But such a problematic identification is required by an interpretation of the innermost core of P as an encoding of the body of P's full beliefs (in the countable case). By the same token, this interpretation (recommended by van Fraassen in [8]) also requires an equally undesirable identification of null measure with epistemic impossibility. It seems more natural to say that P's full beliefs are given by the *union* of P's cores, rather than their intersection. The intersection of cores can, in turn, be seen as the representation of P's *plain* beliefs (or qualitative expectations). The following example intends to provide more intuitive clues supporting this idea. The example illustrates as well the interest of adopting our modified characterization of cores.

Example: The sample space has a countable set of atoms, resulting from the following: in independent trials, a fair coin is flipped until we get a head, and then the trials stop. The set of possible outcomes is indexed by the number of tails $X = (0, 1, 2, ..., n, ..., \omega)$, where ω designates never stopping, i.e., flipping forever and seeing only tails. Evidently $pr(X$ *is finite*$) = 1$ and $pr(X = n) = 2^{-(n+1)}, (n = 0, 1, ...)$, so that (obviously) $pr(X = \omega) = 0$, and this is the only null event, apart from the impossible event. It seems unreasonable in this case to require that a rational agent modeled by P ought to *fully* believe that X is finite.

Notice that in this case it is not enough to interpret full beliefs as the union of cores, as long as cores are defined in terms of an unmodified version of van Fraassen's original definition. In fact, according to that definition, P induces a unique core $U - \omega$. Van Fraassen's condition (A3) impedes considering the entire space as a core. Our modified definition makes this limit case unproblematic. According to our definition, P induces two cores, $U - \omega$, and U. It is also reasonable to say, in the case under consideration, that a finite outcome is *expected*, rather than *fully* believed. This second intuition is captured by our characterization of qualitative expectations as the intersection of cores.

If we learn some proposition A, even one whose probability $pr(A) = 0$, then as long as A intersects the largest core $\mathcal{N}$, P relativised to A has again an elegant theory and its cores are essentially the old cores intersected with A. Thus "revising" by A is well defined.

The notion of revision that thus arises (Bayesian update) satisfies *adjunction, or, right weakening, left logical equivalence*, and both *rational* and *cautious monotony*. We omit details of the logic for lack of space. There are similarities between our logic and the approach using infinitesimal probabilities as for instance [7] and [2]. In the full version we show that Bayesian update falls under the axioms of *cumulative revision*, a qualitative method of change proposed in [2] in order to extend to the iterated case a mapping between two-place probability functions and infinitesimal probability first offered in [7]. Cumulative methods of the type studied in this abstract oc-

cupy a special place in the spectra of methods of change recently studied by computer scientists, economists and philosophers. In fact, in [2] it is shown that the prominent qualitative approaches to belief change are incompatible with some of the properties of cumulative methods – and here we show that Bayesian update does not obey Goldszmidt-Pearl's axioms. Nevertheless in [2] it is also shown that a method proposed in [5] in order to represent the notion of *suppositional change* encoded in two-place functions can be modified and represented as a cumulative method. [9] has an approach using non-standard analysis. In that paper it is shown how we can define a two dimensional, finitely additive probability for *all* pairs of non-empty sets of reals. This eliminates the need to confine ourselves to a σ-field which is a *proper subfamily* of the set of all sets of reals, but at the cost of accepting finite additivity.

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Non-monotonicity from constructing semantic representations

Tim Fernando

Computer Science, Trinity College Dublin

Abstract. A standard approach to non-monotonicity locates the phenomenon in preferences between models, against which certain well-formed formulas or semantic representations (SRs) are interpreted. Such an approach assumes a construction of suitable SRs for natural language discourse — arguably the main challenge in formal linguistics (computational or otherwise). The present work focusses on this assumption, tracing complications associated with presupposition and ambiguity to it. A family of modal logics is outlined, under which non-monotonicity can be analyzed as the failure of a sentence-by-sentence translation of a sequence of natural language sentences to persist; that is, the SR associated with a sentence may, in light of further natural language input, need to be revised. This revision may involve adjustments to background assumptions, implicated in presupposition accommodation.

1 Introduction

There is a considerable body of work predicated on the view that non-monotonicity can be analyzed in terms of preferences between models (e.g. Kraus, Lehmann and Magidor [9]). An indispensable pre-requisite to applications of models to natural language is the translation of natural language discourse into suitable well-formed formulas, henceforth called semantic representations (SRs), which are then interpreted against models. This is not to say that the translation must be specified fully before applications can proceed. It is noteworthy that in *Discourse Representation Theory* (DRT), the SRs of which are called *Discourse Representation Structures* (DRSs), it is the step from natural language to DRSs, rather than that from DRSs to models, that is "the principal challenge" (Kamp [8], page 37). Of course, an argument can be made that non-monotonicity falls outside the scope of DRT (as presented in Kamp and Reyle [7]). Nevertheless, there remains the possibility of non-monotonicity entering in the step from natural language to SR. It is this possibility that the present work explores, motivated by the following examples.

(D1) Statistics show that every eleven seconds a man is mugged here in New York City. We are here today to interview him. [Saturday Night Live, reported in Barwise [1]]

(D2) The King of Buganda is not bald. There is no king of Buganda.

Collecting the SRs (whatever they may be) in a set Φ, it is useful to recognize a second level E of representations, the inputs (e.g. English sentences) to a process of translation into Φ. To condition the translation of a sentence on the sentences surrounding it, let us encode the input/output behavior of a translation process by a set

$$\mathsf{St} \subseteq \bigcup_{n\geq 0} (E^n \times \Phi^n)$$

of pairs $(\vec{e}, \vec{\varphi})$ such that the input $\vec{e}$ may translate to the output $\vec{\varphi}$. Assuming translation proceeds one sentence at a time, it is natural to construe St as a set of *stages*, with the smoothest runs of the process preserving translations determined at earlier stages — that is, normally,

(†) an input/output pair $(e_1 \cdots e_n, \varphi_1 \cdots \varphi_n) \in \mathsf{St}$ arises from the sequence of stages (e_1, φ_1), $(e_1 e_2, \varphi_1 \varphi_2)$, $\ldots$, $(e_1 \cdots e_{n-1}, \varphi_1 \cdots \varphi_{n-1}) \in \mathsf{St}$.

(†) is consistent with the DRS construction algorithm in Kamp and Reyle [7], where φ_i is the DRS constructed for the discourse $e_1 \cdots e_i$ $(1 \leq i \leq n)$.[1]

Abstracting from the particulars of DRT, let us suppose Φ comes with some notion of entailment

$$\vdash \ \subseteq \ \Phi^* \times \Phi$$

(with $\vec{\varphi} \vdash \varphi$ pronounced: "$\vec{\varphi}$ entails φ"), endowing the SRs in Φ with meaning. To lift $\vdash$-entailments of $\vec{\varphi}$ up to $\vec{e}$ along the translation set St, let us extend the set Φ of SRs φ to a set of $\mathcal{L}_\circ(E,\Phi)$-*formulas* A generated according to

$$A \quad ::= \quad \varphi \ \mid \ \langle e \rangle A \ \mid \ \neg A \ \mid \ A \wedge A$$

with modalities $\langle e \rangle$ labeled by expressions $e \in E$, plus negation $\neg$ and conjunction $\wedge$. Let us shorten $\mathcal{L}_\circ(E,\Phi)$ to $\mathcal{L}_\circ$ and identify $\mathcal{L}_\circ$ with the set of $\mathcal{L}_\circ$-formulas. The semantics of $\mathcal{L}_\circ$ is specified relative to an $\mathcal{L}_\circ$-*model* $(\mathsf{St}, \vdash)$ by a "forcing" relation $\Vdash \subseteq \mathsf{St} \times \mathcal{L}_\circ$ as follows, where $(\vec{e},\vec{\varphi}) \in \mathsf{St}$:

(i) an SR φ is forced if $\vdash$-entailed by the output

$$(\vec{e},\vec{\varphi}) \Vdash \varphi \quad \text{iff} \quad \vec{\varphi} \vdash \varphi$$

(ii) $\langle e \rangle A$ is forced by $(\vec{e},\vec{\varphi})$ if some extension of $(\vec{e},\vec{\varphi})$ by e forces A

$$(\vec{e},\vec{\varphi}) \Vdash \langle e \rangle A \quad \text{iff} \quad \text{for some } \varphi,\ (\vec{e}e, \vec{\varphi}\varphi) \Vdash A$$

(where it is understood that $(\vec{e}e, \vec{\varphi}\varphi)$ must also belong to St)

(iii) $\neg$ and $\wedge$ are treated in the usual Boolean manner

$$(\vec{e},\vec{\varphi}) \Vdash \neg A \quad \text{iff} \quad \text{not } (\vec{e},\vec{\varphi}) \Vdash A$$
$$(\vec{e},\vec{\varphi}) \Vdash A \wedge B \quad \text{iff} \quad (\vec{e},\vec{\varphi}) \Vdash A \ \text{ and } \ (\vec{e},\vec{\varphi}) \Vdash B\ .$$

Observe that $\Vdash$ is just Kripke semantics, where the accessibility relation $\xrightarrow{e}$ underlying $\langle e \rangle$ is the binary relation on St such that

$$(\vec{e},\vec{\varphi}) \xrightarrow{e} (\vec{e'},\vec{\varphi'}) \quad \text{iff} \quad \vec{e'} = \vec{e}e \ \text{ and } \ \vec{\varphi'} = \vec{\varphi}\varphi \ \text{ for some } \varphi$$

for all $(\vec{e},\vec{\varphi}), (\vec{e'},\vec{\varphi'}) \in \mathsf{St}$. The persistence of the outputs $\vec{\varphi}$ under $\xrightarrow{e}$ reflects a processing of inputs in accordance with (†). The logic of $\mathcal{L}_\circ$ is investigated in Fernando [2][2] under the assumption that $\vdash$ satisfies certain properties familiar from classical logic, including

$$\text{(R-Weak)} \ \ \frac{\vec{\varphi} \vdash \varphi}{\vec{\varphi}\psi \vdash \varphi}$$

which validates the $\mathcal{L}_\circ$-scheme

$$\varphi \ \supset \ [e]\varphi$$

expressing monotonicity (where $A \supset B$ and $[e]$ abbreviate $\neg(A \wedge \neg B)$ and $\neg\langle e \rangle\neg$ respectively). Neither denying nor adopting (R-Weak), the present work injects non-monotonicity in the passage from E to Φ, generalizing the transitions $\xrightarrow{e}$ in two directions. The first can be carried out within $\mathcal{L}_\circ$-models (section 2); the second involves leaps between $\mathcal{L}_\circ$-models (section 3).

[1] Under reformulations of DRT with an explicit merge operation (e.g. Groenendijk and Stokhof [4]), φ_i might be seen instead as a translation of e_i, given translations $\varphi_1, \ldots, \varphi_{i-1}$ respectively of $e_1, \ldots, e_{i-1}$. The DRS for $e_1 \cdots e_n$ would then be obtained by merging, in sequence, $\varphi_1, \varphi_2, \ldots, \varphi_n$. It is this conception of $(e_1 \cdots e_n, \varphi_1 \cdots \varphi_n)$ which is suitable for the present work. As will become clear below, keeping stages $(\vec{e},\vec{\varphi})$ intact (rather than reducing them to a single DRS) facilitates revision.

[2] The bibliographic reference below contains a *corrigendum*.

2 Interpreting non-monotonicity in $\mathcal{L}_\circ$

The case for revising a translation made in (D1) above can be countered as follows. There is no need to revise the $\forall\exists$-reading of the first sentence, since it is implied by the $\exists\forall$-reading, the difference between which can be incorporated into the translation of the second sentence. On closer inspection, however, one might argue that there is non-monotonicity in (D1): the humor in it afterall lies in retracting the presumption (formed before reading the second sentence) that there is more than one victim of muggings in New York City. Putting such presumptions aside for the moment, let us observe further that there are sentences such as (D3), for which it is far from clear that the disjunction of all of its possible readings is itself a possible reading.

(D3) Danny has not met a Tibetan monk who distributes cognac in Salt Lake City.

Assuming then that the inertia built into $\xrightarrow{e}$ must in certain cases (and in a measured way) be overcome, let us introduce backtracking up to some depth $k \geq 0$ as follows. Let $\sim_k$ be the equivalence relation on Φ^* given by

$$\varphi_n\varphi_{n-1}\cdots\varphi_1 \ \sim_k \ \psi_m\psi_{m-1}\cdots\psi_1 \quad \text{iff} \quad \begin{array}{l} m = n \text{ and} \\ \varphi_i = \psi_i \text{ for } k < i \leq n\ , \end{array}$$

testing for equality modulo the last k components (to the right). This induces binary relations

$$\xrightarrow{e}_k \ = \ \{((\vec{e},\vec{\varphi}),(\vec{e}e,\vec{\psi}\psi)) \mid (\vec{e},\vec{\varphi}) \in \mathsf{St},\ (\vec{e}e,\vec{\psi}\psi) \in \mathsf{St},\ \vec{\varphi} \sim_k \vec{\psi}\}$$

on St, underlying modal operators $\langle e \rangle_k$ for which

$$(\vec{e},\vec{\varphi}) \Vdash \langle e \rangle_k A \quad \text{iff} \quad (\exists\vec{\psi}\psi)\ \vec{\psi} \sim_k \vec{\varphi} \text{ and } (\vec{e}e,\vec{\psi}\psi) \Vdash A \quad [\text{whence } (\vec{e}e,\vec{\psi}\psi) \in \mathsf{St}]\ .$$

Notice that $\sim_0$ is $=$ and consequently $\xrightarrow{e}$ / $\langle e \rangle$ can be understood as abbreviations of the extreme case $\xrightarrow{e}_0$ / $\langle e \rangle_0$. Moreover, since $\sim_k \subseteq \sim_{k+1}$,

$$\langle e \rangle_k A \ \supset \ \langle e \rangle_{k+1} A\ . \tag{1}$$

For a handle on these bounded forms of revision, it is convenient to introduce modal operators $\Diamond_k$ and $\langle e_1 \cdots e_n \rangle$ labeled by sequences $e_1 \cdots e_n \in E^*$, where

$$(\vec{e},\vec{\varphi}) \Vdash \Diamond_k A \quad \text{iff} \quad (\exists\vec{\psi})\ \vec{\psi} \sim_k \vec{\varphi} \text{ and } (\vec{e},\vec{\psi}) \Vdash A$$
$$(\vec{e},\vec{\varphi}) \Vdash \langle e_1 \cdots e_n \rangle A \quad \text{iff} \quad (\exists\psi_1 \cdots \psi_n)\ (\vec{e}e_1 \cdots e_n, \vec{\varphi}\psi_1 \cdots \psi_n) \Vdash A$$

(with which we can associate obvious accessibility relations). Clearly,

$$\langle e_1 \cdots e_k \rangle \langle e \rangle_k A \ \supset \ \langle e_1 \cdots e_k e \rangle A \tag{2}$$
$$\Diamond_k \langle e \rangle A \ \wedge \ \langle e \rangle \top \ \supset \ \langle e \rangle \Diamond_{k+1} A \tag{3}$$

for an $\mathcal{L}_\circ$-formula $\top$ forced by every stage (e.g. $A \supset A$), and

$$\text{if } \vdash \text{ respects (R-Weak)}, \qquad \varphi \ \supset \ [e_1 \cdots e_k][e]_k\varphi\ . \tag{4}$$

The converse of (2) follows from assuming that the domain of St is prefix-closed — i.e. whenever $\vec{e}e \in \mathit{dom}(\mathsf{St})$, $\vec{e} \in \mathit{dom}(\mathsf{St})$. (1) and (2) imply

$$\langle \vec{e} \rangle \langle e \rangle A \ \supset \ \langle \vec{e}e \rangle A\ ,$$

the converse of which requires a stronger assumption than $dom(\mathsf{St})$ being prefix-closed. Recalling (†) from the introduction, let us call St *prefix-closed* if whenever $(\vec{e}e, \vec{\varphi}\varphi) \in \mathsf{St}$, $(\vec{e}, \vec{\varphi}) \in \mathsf{St}$. Prefix-closure of St reduces $\langle e_1 \cdots e_n \rangle$ and $\langle e \rangle_k$ to $\langle e_1 \rangle \cdots \langle e_n \rangle$ and $\Diamond_k \langle e \rangle$ respectively

$$\begin{aligned} \langle e_1 \cdots e_n \rangle A &\equiv \langle e_1 \rangle \cdots \langle e_n \rangle A \\ \langle e \rangle_k A &\equiv \Diamond_k \langle e \rangle A \end{aligned}$$

(where $A \equiv B$ abbreviates $(A \supset B) \wedge (B \supset A)$), and adds to (3) its converse, for

$$\Diamond_k \langle e \rangle A \ \wedge \ \langle e \rangle \top \ \equiv \ \langle e \rangle \Diamond_{k+1} A \ . \tag{5}$$

(5) approximates the commuting squares of *multi-dimensional modal logic* (Marx and Venema [10]). Although the fuss over subscripts k can be sidestepped by passing to $\lim_{k \to \infty} \Diamond_k$ (written $\Diamond$ in Fernando [2]), the blemish $\langle e \rangle \top$ is harder to overlook.

The $\mathcal{L}_\circ$-formula $\langle e \rangle \top$ is, however, quite interesting in its own right, constituting, as it does, a candidate for the *presupposition of* e, conceived as a precondition for translation. The idea is that presupposition failure of e at a stage $(\vec{e}, \vec{\varphi})$ signals the absence of an SR φ for which $(\vec{e}e, \vec{\varphi}\varphi) \in \mathsf{St}$ — i.e. $(\vec{e}, \vec{\varphi}) \not\Vdash \langle e \rangle \top$.[3] The familiar negation test can be stated concisely as

$$\langle \dot{\neg} e \rangle \top \ \equiv \ \langle e \rangle \top$$

for some negation operation $\dot{\neg}$ on E, distinct from the connective $\neg$ on $\mathcal{L}_\circ$-formulas. Furthermore, the presupposition projection behavior of conjunction $\dot{\wedge}$ and implication $\dot{\supset}$ predicted by Heim [6] can be verified by arranging

$$\begin{aligned} \langle e \dot{\wedge} e' \rangle \top &\equiv \langle e \rangle \langle e' \rangle \top \\ \langle e \dot{\supset} e' \rangle \top &\equiv \langle e \rangle \langle e' \rangle \top \end{aligned}$$

(again being careful not to confuse $\mathcal{L}_\circ$-connectives with the dotted E-connectives). These equivalences hold if $\overset{e \dot{\wedge} e'}{\rightarrow}$ and $\overset{e \dot{\supset} e'}{\rightarrow}$ are defined sequentially from $\overset{e}{\rightarrow}$ and $\overset{e'}{\rightarrow}$ so that say,

$$\begin{aligned} \overset{e \dot{\wedge} e'}{\rightarrow} \ = \ \{((\vec{e}, \vec{\varphi}), (\vec{e}(e \dot{\wedge} e'), \vec{\varphi}(\varphi \cdot \psi))) \ : \ (\vec{e}(e \dot{\wedge} e'), \vec{\varphi}(\varphi \cdot \psi)) \in \mathsf{St} \\ \text{and } (\vec{e}, \vec{\varphi}) \overset{e}{\rightarrow} (\vec{e}e, \vec{\varphi}\varphi) \overset{e'}{\rightarrow} (\vec{e}ee', \vec{\varphi}\varphi\psi)\} \end{aligned}$$

for some binary connective $\cdot$ on Φ. The crucial difference with Heim [6] is the use of an extra level E of representations, allowing presupposition to be linked with anaphora resolution (understood as the construction of suitable SRs), as suggested by the *familiarity condition* of Heim [5] and developed at length in DRT by van der Sandt [11]. Although the role of entailments $\vdash$ in forcing $\langle e \rangle \top$ may appear vacuous, $\vdash$ can exert some influence through constraints between St and $\vdash$ stipulated for the $\mathcal{L}_\circ$-models $(\mathsf{St}, \vdash)$ of interest. Consider, for instance, the first sentence of discourse (D2) in the introduction, call it $\hat{e}$. A plausible constraint to impose is that $\hat{e}$ presupposes the existence of a Bugandan king unless the contrary is known. Assuming $\hat{\varphi}$ is an SR asserting a Bugandan king exists and $\dot{\neg}\hat{\varphi}$ is an SR denying that he does, this constraint can be expressed by the $\mathcal{L}_\circ$-formula

$$\neg \dot{\neg} \hat{\varphi} \ \supset \ (\langle \hat{e} \rangle \top \equiv \hat{\varphi}) \ . \tag{6}$$

[3] A complication arising from ambiguity is interference between multiple readings: *all* readings of e (under St) must suffer from presupposition failure if no translation of e is possible. This fine point can be finessed by passing to a more selective translation process St', restricted to the reading of e in question.

The non-monotonicity from $\neg \dot{\neg} \hat{\varphi}$ in (6) aside,[4] notice that if the empty sequence ϵ entails neither $\hat{\varphi}$ nor $\dot{\neg}\hat{\varphi}$, then (6) implies presupposition failure of $\hat{e}$ at (ϵ, ϵ) — i.e. $(\epsilon, \epsilon) \not\Vdash \langle \hat{e} \rangle \top$.

3 Non-monotonicity from leaps between $\mathcal{L}_\circ$-models

Presupposition failure is tricky in part because it need not end interpretation, but rather usher in a process of repair commonly called accommodation. In the present framework, a failure $(\vec{e}, \vec{\varphi}) \not\Vdash \langle e \rangle \top$ might be repaired by changing the particular $\mathcal{L}_\circ$-model $(\mathsf{St}, \vdash)$ underlying $\Vdash$ to an $\mathcal{L}_\circ$-model $(\mathsf{St}', \vdash')$ for which $(\vec{e}, \vec{\varphi}) \Vdash' \langle e \rangle \top$. Returning to sentence $\hat{e}$ from (D2), global accommodation of $\hat{\varphi}$ can be modeled as a leap to an $\mathcal{L}_\circ$-model $(\mathsf{St}', \vdash')$ which takes $\hat{\varphi}$ for granted — say,

$$\begin{aligned} \mathsf{St}' &= \{(\hat{e}\vec{e}, \varphi\vec{\varphi}) \ : \ (\hat{\varphi}\hat{e}\vec{e}, \hat{\varphi}\varphi\vec{\varphi}) \in \mathsf{St}\} \\ \vdash' &= \{(\vec{\varphi}, \varphi) \ : \ \hat{\varphi}\vec{\varphi} \vdash \varphi\} \ . \end{aligned}$$

Such leaps between $\mathcal{L}_\circ$-models can be analyzed in an expansion $\mathcal{L}$ of $\mathcal{L}_\circ$, where an $\mathcal{L}$-model is a pair $(\mathsf{ST}, \{\vdash_\alpha\}_{\alpha \in I})$ such that $\mathsf{ST} \subseteq \bigcup_{n \geq 0} (E^n \times \Phi^n \times I)$ and for every $\alpha \in I$, $(\mathsf{ST}_\alpha, \vdash_\alpha)$ is an $\mathcal{L}_\circ$-model, with (by definition)

$$\mathsf{ST}_\alpha \ = \ \{(\vec{e}, \vec{\varphi}) \ : \ (\vec{e}, \vec{\varphi}, \alpha) \in \mathsf{ST}\} \ .$$

Reifying $\mathcal{L}_\circ$-models as indices in I, we can extend $\mathcal{L}_\circ$ conservatively by defining a forcing predicate $\Vdash$ relative to ST such that for all $A \in \mathcal{L}_\circ$ and $(\vec{e}, \vec{\varphi}, \alpha) \in \mathsf{ST}$,

$$(\vec{e}, \vec{\varphi}, \alpha) \Vdash A \quad \text{iff} \quad (\vec{e}, \vec{\varphi}) \Vdash_\alpha A$$

where $\Vdash_\alpha \subseteq \mathsf{ST}_\alpha \times \mathcal{L}_\circ$ is the $\mathcal{L}_\circ$-forcing predicate for $(\mathsf{ST}_\alpha, \vdash_\alpha)$. The reason for stepping up to $\mathcal{L}$ is to form $\mathcal{L}$-formulas such as $\langle\!\langle e \rangle\!\rangle A$ where

$$(\vec{e}, \vec{\varphi}, \alpha) \Vdash \langle\!\langle e \rangle\!\rangle A \quad \text{iff} \quad (\exists \psi, \beta) \ (\vec{e}e, \vec{\varphi}\psi, \beta) \Vdash A$$

or, constraining leaps through a binary predicate R on I,

$$(\vec{e}, \vec{\varphi}, \alpha) \Vdash \langle\!\langle e \rangle\!\rangle_R A \quad \text{iff} \quad (\exists \psi, \beta) \ R(\alpha, \beta) \text{ and } (\vec{e}e, \vec{\varphi}\psi, \beta) \Vdash A \ .$$

Notice that $\langle e \rangle$ is just $\langle\!\langle e \rangle\!\rangle_=$ (with $R(\alpha, \beta)$ iff $\alpha = \beta$), while $\langle\!\langle e \rangle\!\rangle$ is $\langle\!\langle e \rangle\!\rangle_{I \times I}$. Going back to $\hat{e}$ and (D2), with $(\mathsf{ST}_\alpha, \vdash_\alpha) = (\mathsf{St}, \vdash)$, $(\mathsf{ST}_\beta, \vdash_\beta) = (\mathsf{St}', \vdash')$ and $I = \{\alpha, \beta\}$, the point is that although $(\epsilon, \epsilon) \not\Vdash_\alpha \langle \hat{e} \rangle \top$, $(\epsilon, \epsilon, \alpha) \Vdash \langle\!\langle \hat{e} \rangle\!\rangle \top$, and indeed $(\epsilon, \epsilon, \alpha) \Vdash \langle\!\langle \hat{e} \rangle\!\rangle A \equiv \langle \hat{\varphi} \rangle \langle \hat{e} \rangle A$ for all $\mathcal{L}_\circ$-formulas A. Notice that the second sentence of (D2) suggests presupposition cancellation (Gazdar [3]), retracting the default $\hat{\varphi}$ by leaping out of β. If $I = \{\alpha, \beta\}$, then that leap can only land back in α, from which it follows that ST_α is not prefix-closed. Alternatively, I might include a further index γ such that $\epsilon \vdash_\gamma \dot{\neg}\hat{\varphi}$, in which case we could have avoided jumping around, had we applied at the outset the $\mathcal{L}_\circ$-model $(\mathsf{ST}_\gamma, \vdash_\gamma)$ to (D2). But how could we have known that before translating (D2)? It would seem we better be prepared to leap between $\mathcal{L}_\circ$-models.

As with $\langle e \rangle_k$ and $\Diamond_k$, prefix-closure supports a decomposition of $\langle\!\langle e \rangle\!\rangle_R$ into $\langle\!\langle R \rangle\!\rangle \langle e \rangle$, where

$$(\vec{e}, \vec{\varphi}, \alpha) \Vdash \langle\!\langle R \rangle\!\rangle A \quad \text{iff} \quad (\exists \beta) \ R(\alpha, \beta) \text{ and } (\vec{e}, \vec{\varphi}, \beta) \Vdash A \ .$$

[4] The presumption discussed above for the first sentence of (D1) can be formulated in a similar manner as the $\mathcal{L}_\circ$-constraint $\neg \dot{\neg} \varphi_1 \ \supset \ [e_1]\varphi_1$, where e_1 is the first sentence of (D1), φ_1 is the aforementioned presumption, and $\dot{\neg}\varphi_1$ is the negation in Φ of φ_1.

Here, and in the sequel, it is convenient to assume that $E \supseteq \Phi$, replacing, if necessary, E with $E \cup \Phi$ and translating (in St) the SRs to themselves. See assumption $(\mathrm{a}_\circ)$ in Fernando [2].

(Reducing $\langle\!\langle e \rangle\!\rangle_R$ to $\langle e \rangle_k \langle\!\langle R \rangle\!\rangle$ is again blocked by the possibility of presupposition failure.) What stories one can tell with the supply of modalities $\langle e \rangle, \Diamond_k, \langle\!\langle R \rangle\!\rangle$ remains to be seen. It is easy enough to generalize, for instance, $\langle\!\langle R \rangle\!\rangle$ so that R takes not only α and β as arguments, but also the initial stage $(\vec{e}, \vec{\varphi})$. It is not obvious to me, however, what would be gained in empirical coverage by such generalizations.

4 Conclusion

Two kinds of revision were considered above: changes to the SRs $\vec{\varphi}$ associated with inputs $\vec{e}$ (section 2), and changes to the implicit context determining translation-entailments pairs (section 3). Let us close by noting how to work notions of preference into either. Preferences can be built into modifications $\Diamond_k^p$ of $\Diamond_k$ as follows

$$(\vec{e}, \vec{\varphi}) \mid\!\!\vdash \Diamond_k^p A \quad \text{iff} \quad (\exists \vec{\psi})\ \vec{\psi} \sim_k \vec{\varphi},\ \vec{\psi} \text{ is preferable to } \vec{\varphi} \text{ as a reading of } \vec{e}$$
$$\text{and } (\vec{e}, \vec{\psi}) \mid\!\!\vdash A\ .$$

Non-monotonicity may then take the form of preferring $(\vec{e}, \vec{\varphi})$ to $(\vec{e}, \vec{\psi})$, but $(\vec{e}e, \vec{\psi}\psi)$ to $(\vec{e}e, \vec{\varphi}\varphi)$ (if not perhaps $(\vec{e}, \vec{\varphi}) \not\mid\!\!\vdash \langle e \rangle \top$). Similarly for $\langle\!\langle R \rangle\!\rangle^p$ and $\langle\!\langle R \rangle\!\rangle$, allowing for changes in I. How these preferences compose is one of many questions to explore.

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Identification Language Games[1]

Peter Krause
IMS Stuttgart

Abstract

Identification dialogues are inquiries into which individual a speaker intends to refer to. Typical identification dialogues occur when a riddle is solved and when a reference is clarified in a subdialogue. Here, the simplest kind of identification dialogue is studied abstractly. A version of discourse representation theory (DRT) with presuppositions and an epistemic operator; and a specification of the propositional attitudes of the participants together with anchoring relations are used to specify the scoreboard of a language game of identification dialogues with two participants, the identifier and the informant. The rules are based on the standard semantics for the representations.

A *defeasible* notion of *knowing which* object is meant can be formulated. The meaning of the locution *which one X is depends on which one Y is.* is specified.

1 Introduction

By *identification dialogue* in this paper I will mean a dialogue exchange between two partners in which one of them, the identifier, tries to fix the reference of a discourse entity that the other participant, the informant, is talking about. It will be assumed that both participants have and communicate only true information. For the identifier, it is required that the subjects in his initial information state all derive from distinct objects and that he possesses internal anchor, although the content of the anchors will not be specified in the discussion. Given this description of the pragmatic situation, it is clear that an account of the propositional attitudes of the conversationalists is needed. The analysis will be based on the formalism for propositional attitudes of (Kamp 1990). As in (Groenendijk 1999), a simple language game will be described that relies on dynamic semantics. An epistemic interpretation for identification questions is used that relates two information states. Identification dialogues often involve nested question-answer patterns. One task for an analysis of identification questions is to explain which subordinate questions can occur, given an initial identification question. Based on the semantics, a notion of dependence between questions is defined which is then used for the definition of the preconditions of subquestion moves.
The paper is organized as follows. In section (2), a reconstruction of the language game of identifying references is given, by a specification of the representation language (2.2), semantic definitions (2.3), and descriptions of the possible moves (2.4). Section (3) discusses identification question that are embedded under *know.*

2 Scoreboard and Rules

2.1 The scoreboard

The scoreboard consists of the identifier's and the informant's part. The scoreboard S_{Id} of the identifier Id is a quadruple

$$\langle K_1, K_2, CG, A \rangle$$

[1] Thanks to Jan van Kuppevelt, Uwe Reyle, Henk Zeevat and Ede Zimmermann for discussions related to the topic of this paper.

Here K_1 is a DRS representing the initial knowledge of Id about the domain. K_1 must support distinctness of all pairs of discourse referents in $U(K_1)$. All discourse referents in $U(K_1)$ are assumed to be anchored. The internal anchors aren't specified, however, because it is a difficult problem to decide how much information should be part of the anchoring conditions[2]. K_2 is a DRS representing extensions to B's knowledge during conversation, for instance information about questions that is not part of the common ground, and discourse individuals that are inferred from information in the common ground. CG is a DRS representing the common ground. It contains discourse referents for questions that have been introduced during the conversation[3] and the content of assertions and presuppositions made by the informant and the identifier during the conversation. A is a list of anchors linking discourse referents in CG to internally anchored referents in K_1. The parts of the identifier's scoreboard will be referred to using $S_{Id} : K_1$, $S_{Id} : K_2$, $S_{Id} : CG$, $S_{Id} : A$, and analoguously for the informant's scoreboard. Let A' be the DRS with empty universe that contains an equation for each anchor in A[4]. Let us denote the combined DRS $K_1 \circ A' \circ CG$ by K^{com} for further reference[5].
The scoreboard of the informant has the same structure. It will be assumed throughout that the versions of the common ground of the two participants differ maximally in that one may be an alphabetic variant of the other. The rules specifying the effects of game moves ensure that the CGs cannot diverge. This is of course an idealization[6].

2.2 Representation language

The components of the scoreboard are DRSs. The standard basic DRT syntax for DRSs K is used in both the linear notation and the two-dimensional notation. In addition, the following constructs are used[7]:

- $\delta(x, K)$ (definite descriptions)
- $IdQ(\delta(x, K))$ (identification questions)
- $K?$ (decision questions)
- $Q; Q = QT$ (question referent introduction)
- $RELANCH(x, y)$ (relative anchors)
- $\Diamond\, K$ (epistemic might)
- $KNOW(Q)$ (knowing who/whether)

2.3 Semantics

First, the standard update semantics for the basic DRT language with a presupposition operator and the epistemic modality is repeated (Def. 1). A similar definition can be found in Dekker (1993), except for the presupposition clause. The might-operator $\Diamond$ has been introduced by (Veltman 1996). Then the semantic notions for questions are defined.
In the following, σ denotes a set of pairs of worlds and partial variable assignments, or an information state. The minimal state σ_0 is $W \times \{\epsilon\}$, where ϵ is the empty assignment[8].

[2] In the application to localization dialogues, one option is to let the internal anchors specify coordinates on a map. This guarantees unique identification of spatial entities.

[3] In this sense, it functions like a stack of questions under discussion

[4] For instance, if A contains $RELANCH(x_{A1}, y_2), RELANCH(x_{A2}, y_5)$, then A' is $x_{A1} = y_2$; $x_{A2} = y_5$

[5] This combined DRS is the basis for the definition of some semantic notions below. $\circ$ denotes DRS merge

[6] In particular, it has to be assumed that the participants always accept each other's moves.

[7] K and QT range over DRSs and question terms (either identification or decision questions), respectively.

[8] See Dekker (1993) for the relevant auxiliary definitions

Definition 1 (Update semantics for DRT with might)

- $\sigma[\![x_i]\!] = \{\langle w, g\rangle |\ \exists g' \langle w, g'\rangle \in \sigma \text{ and } g' \prec_{x_i} g \text{ and } g(x_i) \in \mathcal{U}\}$
- $\sigma[\![R(\delta(x_1, K_1) \ldots \delta(x_n, K_n))]\!] = \begin{cases} \{\langle w, g\rangle \in \sigma |\ \langle g(x_1) \ldots\ g(x_n)\rangle \in F(R)(w)\} \\ \quad \text{if } x_1 \ldots\ x_n \in Dom(\sigma) \text{ and } \sigma \models K_i \\ \text{undefined otherwise} \end{cases}$
- $\sigma[\![\delta(x_1, K_1) = \delta(x_2, K_2)]\!] = \begin{cases} \{\langle w, g\rangle \in \sigma |\ g(x_1) = g(x_2)\} \\ \quad \text{if } x_1, x_2 \in Dom(\sigma) \text{ and } \sigma \models K_1, K_2 \\ \text{undefined otherwise} \end{cases}$
- $\sigma[\![K_1; K_2]\!] = \sigma[\![K_1]\!][\![K_2]\!]$
- $\sigma[\![\neg D]\!] = \sigma - \sigma[\![D]\!]$
- $\sigma[\![K_1 \Rightarrow K_2]\!] = \{i \in \sigma |\ \forall i_1 \in \{i\}[\![K_1]\!]\ \exists i_2\ i_2 \in i_1[\![K_2]\!]\}$
- $\sigma[\![\Diamond K]\!] = \begin{cases} \sigma \text{ if } \sigma[\![K]\!] \neq \emptyset \\ \emptyset \text{ otherwise} \end{cases}$

The interpretation of questions is defined with respect to the entire scoreboard.

Definition 2 (Alternative set of an identification question)
$alt(IdQ(\delta_{CG}(x, K)), S_{Id}) =$
$\{v \in Dom(S_{Id} : K_1) |\ \sigma_0[\![S_{Id} : K^{com}; \Diamond v = x_{Inf}]\!] \neq \emptyset\}$

Definition 3 (Alternative set of a decision question)
$alt(K?, S) = \begin{cases} \{[\![K]\!], [\![\neg K]\!]\} \text{ if neither } S_{Id} : K^{com} \models K \text{ nor } S_{Id} : K^{com} \models \neg K \\ \emptyset \text{ otherwise} \end{cases}$

The clause for identification questions specifies that any candidate that might be the correct anchor for the variable in question belongs to the alternatives. There is no one-to-one correspondence of the alternatives with the linguistic answers that the informant may give, because the informant in general does not know whether his answer will lead to an identification. For decision questions, the alternatives are given by the two answer possibilities.

Definition 4 (Knowing which)
$S_{Id} \models KNOW(Id, IdQ(\delta_{CG}(x, K)))$ *iff* $|alt(IdQ(\delta_{CG}(x, K), S_{Id}))| = 1$.

Definition 5 (Knowing whether)
$S_{Id} \models KNOW(Id, K?)$ *iff* $S_{Id} : K^{com} \models K$ *or* $S_{Id} : K^{com} \models \neg K$

The notion of dependence is the most important tool for analysing the structure of the dialogue in terms of questions as in van Kuppevelt (1991). A question is useful for another question if at least one conclusive answer to the first question narrows down the alternatives for the second question.

Definition 6 (Dependence of a question on another question)
Let Q_1 be a question that is not yet resolved wrt to the scoreboard S. Q_1 depends on Q_2 wrt S_{Id},
$S_{Id} \models depends(Q_1, Q_2)$ *iff*

- *Q_2 an identification question $IdQ(x_{Inf})$ and*
  $\exists v \in alt(Q_2, S_{Id}) :\ alt(Q_1, S_{Id} \circ RELANCH(x_{Inf}, v)) \subset alt(Q_1, S_{Id})$
- *Q_2 is a decision question $K?$ and either*
  $alt(Q_1, \langle K_1, CG, A, K_2 \circ K\rangle) \subset alt(Q_1, \langle K_1, CG, A, K_2\rangle)$
  or
  $alt(Q_1, \langle K_1, CG, A, K_2 \circ \neg K\rangle) \subset alt(Q_1, \langle K_1, CG, A, K_2\rangle)$

2.4 The Game Moves

The moves of the dialogue game are described in terms of their logical form (a move type name with a number of arguments in DRT syntax), preconditions and effects. The move types $INIT$ (first mention of the discourse entity in question by Inf), ASK_{dec} (Id asks a yes/no question) and $ANSWER$ (the informant answers the previous question) do not require much discussion here. I rather concentrate on ASK_{idq} (Id asks an identification question) and the dialogue control move types NYI, ID, $UNDERSTAND$ and $REPORTID$. The inquiry starts with an initial identification question ASK_{idq}. To distinguish the initial identification question from auxiliary ones, a special condition $tcq(Q)$ is added to the common ground as one of the effects of this move (a question variable Q is introduced together with an equation, see the syntactic constructs). This condition does not have a semantics, it only serves to control the game. The preconditions for $ASK_{idq}(IdQ(\delta_{CG}(x,K)))$ require that the question may not yet be resolved ($\neg KNOW(Id, IdQ(\delta_{CG}(x,K)))$). If there is already a question Q with a condition $tcq(Q)$, ASK_{idq} is subject to a further precondition: the new identification question must contribute to finding an answer to an identification question that is already present. In other words, an old identification question must depend on the new one: $S_{Id} \models depend(Q_{old}, Q_{new})$. The old identification question here can either be the initial one, or another identification question on which the initial one depends, possibly indirectly. The third precondition for $ASK_{idq}(IdQ(\delta_{CG}(x,K)))$ concerns the identifiability of the discourse entity by the informant. There may be only one antecedent for the definite description $\delta_{CG}(x,K)$ with respect to the common ground. Of course this condition may be satisfied although the definite is not unique with respect to the informant's overall knowledge. The move type $ANSWER(Q,K)$ has a parameter for the answered question. The second parameter must be either the positive or negative alternative in the case of a decision question or a proposition about the questioned referent of an identification question. A proposition about a referent is represented by a DRS in which the referent occurs free, or a definite description that must be resolved to it. The informant cannot do any better than provide an informative assertion about the questioned referent, because he cannot be sure that the information will be identifying with respect to the identifier's information state. The identifier move $NYI(K)$ (acronym for *not yet identified*) signals insufficient information about a salient identification question. Its content argument K is $\neg KNOW(Id, IdQ(\delta_{CG}(x,K)))$ for some variable x in (the identifier's version of) the common ground. The preconditions are: (i) the identification question about x is in $S_{Id} : K_2$, (ii) it is not yet resolved (otherwise the content of the move would not be supported, contradicting the quality maxim). It is not required that the question be in the common ground, it may be an effect of NYI to add the question to the common ground. Besides uttering a sentence that immediately corresponds to the content argument, the move can also be expressed by uttering any sentence that entails that the identifier has not yet resolved the identification question, such as *There are two K*. The main effect of the move is the creation of an obligation to answer the identification question about x next. This can be implemented using operations on a QUD stack as in Ginzburg (1996). $ID(x_{CG}, x_{Id})$ is a non-linguistic move. The identifier adds an identification assumption $RELANCH(x_{CG}, x_{Id})$ to his $S_{Id} : A$ when the identification question about x_{CG} becomes resolved: the precondition is that $S_{Id} \models KNOW(IdQ(\delta_{CG}(x,K)))$ for an identification question in $S_{Id} : A$. If the identification question was also present in the common ground, then the ID move must be followed by an $UNDERSTAND$ and a $REPORTID$ move. $UNDERSTAND$ signals to the informant that an identification has been made, without telling him which one. This is done by $REPORTID$. The syntax for $REPORTID$ is $REPORTID(\delta_{Inf}(x), \delta_{Id}(y))$. The precondition is that the

corresponding identification has been made. The function of $REPORTID$ is to give the informant feedback about the identification. The second argument is a definite description the existence presupposition of which is not satisfied with respect to the common ground, but only with respect to the identifier's knowledge. As a result, the informant will accommodate the descriptive content of the definite in his version of the common ground and check consistency with his own information. An obligation for the informant to $CONFIRM$ or disconfirm the identification is created.

2.5 Start and termination of games

The game is started by an $INIT$ move by the informant. The identification language game is over if the initial, topic-constituting identification question is resolved for the identifier and his identification has been confirmed by the informant. In the final state of the game, there may remain pending identification questions that have been raised as subquestions of the initial identification questions.

3 Identifying knowledge and question dependence

Are the notions of *knowing who* and of dependence specified above linguistically adequate ?

Knowing who The notion of *knowing who* specified above has an interesting property. Suppose the identifier knows who $\delta(x,K)$ is at a given stage of the language game. Suppose further that he learns, from the informant or from another source, that there is another individual that satisfies the properties ascribed to x in K. This will lead him to extend the universe of $S_{Id} : K_1$ accordingly, and the resulting scoreboard S'_{Id} will no longer support that he knows who $\delta(x,K)$ is. For instance, a detective may claim to know the identity of the murderer as soon as only one of the persons he suspects still satisfies all the properties that he ascribes to the murderer. But the claim may have to be retracted when a new suspect comes to the detective's attention.
A potential problem for the treatment of *knowing who* would be the problem of well-foundedness of identification. In principle, the identifier could always inquire further, questioning the identification of the subjects in terms of which another subject has been identified. The answer to this objection is that it has been assumed at the outset that the identifier has suitable anchors for his subjects. There are clear-cut situations in which this does not seem to be too much of an idealization, e.g. cases of diagrams in a coordinate system. No claim is implied that such a foundation can always be found.

Dependence The definition of dependence requires that at least one successful answer to the first question truly narrows down the alternatives for the dependent question. This notion of dependence is quite weak. There are two conceivable alternatives: requiring that all successful answers narrow down the alternatives for the dependent question, or even that there is a functional relation between the alternatives for the first and the second question. Both seem too strong to capture the semantics of the locution *who t_1 is depends on who t_2 is*. For instance, consider the following sentence.

Who is the murderer depends on who was in the house.

It can be truthfully uttered by a detective even if he neither believes that not all of the suspects may have been in the house nor has enough information to directly identify the culprit once he knows who was in the house.

4 Conclusion

This paper is an attempt to specify adequate rules for the language game of identification dialogues. The pragmatic rules for the move types are closely connected to the semantics of the scoreboard, and it seems possible to specify explicit rules for assigning move types to utterances on this basis.
There are various possibilities for further investigation. The repertoire of move types can be extended in various ways and move definitions may be refined. The more general question what a satisfactory answer to a *who*-question is and the related problem of specifying a *general* semantics of *knowing who* that also takes into account cases in which one can say that an agent knows who X is although the information is not sufficient to identify X have not been addressed here. See Gerbrandy (1997) for a recent discussion.

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Explaining Presupposition Triggers

Henk Zeevat

Summary

The paper proposes three revisions to the standard views of presupposition: the employment of optimality theory for the defaults and preferences, the admission of weak antecedents for presupposition resolution/satisfaction and a fine-grained classification of presupposition triggers, based on the availability of expression alternatives and the logical requirement of the presupposition. The treatment is able of dealing with a range of phenomena that are outside the scope of any current presupposition theory. A fuller version of the paper is available through

http://earth.hum.uva.nl/ henk

The particle *too* can be a starting point for the discussion. (1)is Kripke's example to show that (at least some) presupposition triggers must be taken as anaphors to specific information in the context. Otherwise, given that millions have dinner in New York every evening, the presupposition is trivial, which conflicts with our intuition about the example.

(1) John has dinner in New York too.

But the example has other interesting properties as well. It is a presupposition that does not accommodate (against theories of presupposition that have accommodation as a general possibility). If it would, the observation that more is required than the truth of the proposition that somebody apart from John has dinner in New York would not follow: this is precisely what would have to be accommodated.

Second, the antecedent need not be a direct ingredient of the context. It is sufficient that the other New York eater is reported or suggested. E.g. (2)

(2) Harry may well stay in New York for dinner.

is a good antecedent. Also (3):

(3) John believes that Mary will eat in New York.

(3) also illustrates a third property: partial resolution. The antecedent only mentions eating and does not strictly imply that a dinner is involved (a lunch

or a quick snack would be possibilities). The process of finding the antecedent adds the extra information that Mary will have dinner. The process is one of finding an antecedent that only partly meets the specification and of adapting it to become a full antecedent.

A fourth property of the particle *too* is that it is not possible to omit it when it has a suitable occurrence in the context. When it is omitted the total discourse becomes strange, though perhaps not always equally strange. It can sometimes be replaced by other markers (e.g. *also*) but the bare version of the sentence is not appropriate if the version with *too* is.

All of these four properties are unexplained if we take the best theories on the market like Heim and Van der Sandt. Weak Antecedents are out, accommodation is allowed without restriction, partial resolution is ruled out by the formalisations and the theories have nothing to say about about the obligatory nature of *too*.

1 Old Material

In order to deal with Weak Antecedents, it seems necessary to allow material that is not in the common ground as such but is believed or suggested in the common ground. It may be the speaker, but it may also be the hearer or another person whose beliefs have been attributed in the common ground. Also, it is not necessary that the attitude is belief or knowledge. Dreams, presentations of plans and desires and of possibilities all seem to provide proper antecedents for some triggers. Three examples are given below.

A corrects his conversation partner :

(4) The king of France is not bald, France is a republic.

A presupposes the king of France, even though he has not the slightest inclination to assent himself to the statement that there is such a person.

(5) A: John thinks Mary has gone to Bill's party.
B: Carol has gone there too.

(6) A: John dreamt that his car was stolen.
B: My car was stolen too.

This wider range of possibilities is of course present in the pre-Karttunen linguistic literature on presupposition, but appears to have been neglected in the more formal literature for a very simple reason: many of the key triggers in that literature appear to lack the possibility of such antecedents. Definite descriptions, names, factives, and lexical presuppositions prima facie do not have

them. Questions, many particles, clefts and intonationally marked topic typically fall on the other side. Anaphoric pronouns belong to the first group. The characterisation of the range of attitudes that generate weak antecedents is roughly[1] what Giannakidou has labelled the veridical contexts: those that do not license negative polarity items.

The explanation of the difference between the triggers is straightforward. Next to their triggering properties, the triggers also have other semantical properties that are intertwined with their presuppositional properties. Definite descriptions, names and anaphoric pronouns are referring expressions, a noun like bachelor predicates a property of an individual, a factive states something about the mind of its subject, etc. And crucially, the object that the referring trigger refers to is the object required to meet the presupposition that is triggered, the proposition in the mind of the subject that is involved in the mental part of the factive is the same as the presupposed proposition and the property presupposed by a lexical trigger is also part of the predication. For this reason, it cannot be that the presupposition is entirely absent in the local context of the trigger: the reference would then fail to exist, the attitude would not be possible or the predicate would not hold.

That part of the semantics of the trigger which is shared with the presupposition I call its *requirement*. Notice that this is not meant as yet another independent specification of a lexical property of the triggers, but just a consequence of properly spelling out the semantical function of the item and comparing it with the presupposition. The requirement has two roles to play in the theory of presupposition: it must explain why a trigger use of some triggers in a context where the requirement is not met leads to an uninterpretable sentence and it must further explain why some triggers but not others resolve to inaccessible contexts. The requirement therefore —and not the presupposition— is what turns a pragmatic presupposition into a semantic presupposition. When the requirement equals the presupposition (or is stronger), weak antecedents are out. When the requirement is empty, weak antecedents appear unrestrictedly. The interesting case is when the requirement is weaker than the presupposition. Some weak antecedents are then allowed, but the phenomenon is restricted. Compare (7).

(7) John believes that p and he regrets that p.

Here weak resolution occurs and the requirement (that John believes that p) is met. But we do not predict that accommodation of *John believes that p* is possible, when there is no weak antecedent. If (8)occurs in isolation, we must infer that p.

(8) John believes that p.

In contrast, (9)

[1]There is a considerable overlap with the distribution of negative polarity items, but there is not an exact match: e.g. suggest in Modern Greek takes negative polarity items.

(9) John believes that p and he knows that p.

also allows the same resolution, but the resolution is not sufficient for entailing the requirement $(p \wedge Bp)$. So, the only option is global accommodation or global resolution. Other examples are given for names, anaphora and definite descriptions in the full paper.

2 Optimality Theory

Blutner99 is the first to notice that the defaults and preferences that are so characteristic of presupposition can be adequately captured by the soft constraints and the constraint ordering of optimality theory. He proposes two constraints: **Do Not Accommodate** and **Strength** ordered as indicated. The accommodation constraint prevents accommodation when it is not necessary, the strength constraint prefers the reading of the sentence that gives most information. An absolute constraint of **Consistency** can be added, to obtain local accommodations, when global ones are not consistent. Together the system provides a reconstruction and an improvement of the theory of Van der Sandt92. The improvements are avoiding accommodation in downward entailing subcontexts and the smooth incorporation of partial resolution.

If Optimality Theory can be applied to presupposition interpretation, it is a natural question whether it is possible to apply it to the generation of presupposition triggers as well. In fact, one might first want to be sure that the so-called interpretation principles are not really generation principles in disguise. But for a principle like: do not accommodate, this does not seem to be possible. It is contextual variation that is responsible for the selection of different interpretations of (10)and the context seems to have little influence on its form.

(10) Bill believes that John regrets that Mary left.

The decision to relegate the communication of some content to presupposition accommodation rather than to a separate prior assertion involves considerations of efficiency and even politeness. Though the reconstruction of these considerations plays a role in the interpretation of accommodating examples, the recognition of them does not seem to be the crucial factor: that is the absence of an antecedent. **Strength** is likewise so much a question of choosing between possible interpretations that a corresponding generation principle is hard to imagine.

There is a class of presupposition triggers that are obligatory. Intonational marking, discourse particles, pronouns, another, *a different*, some uses of definite descriptions seem to fall into the class.

The basic observation is that (11) cannot normally be replaced by the sentence without *too* in a context where *too* appears.

(11) John is in Spain too.

This is familiar from the generation of referential expressions. There is a hierarchy of referential devices which can be selected only if the application criteria of the classes appearing in the hierarchy above it do not apply. I omit the full discussion in this abstract. The hierarchy leads to at least two principles: **ParseOld** and **ParseOther**. The first requires the marking of old material as old and using a trigger is nearly always a way of doing so with respect to the presupposition. **ParseOther** demands the use of an other-marker in case there is a an old element with the same description in the context. Typical other-markers are *another*, *too*, *also* and *as well*.

Both principles should be thought of as primarily psychological. It is well established that the perceptual system is biased to the identification of what is similar and nothing seems more functional than controlled use of this bias: inhibit it when necessary and exploit it when it has to identify. The last function also increases efficiency: second occurrences can be much shorter.

The two principles affect the distribution of triggers: they force the use of an item from the relevant class of triggers when the conditions for its application occur.

3 Blutner's Theorem

Blutner in still unpublished work provides the following explanation of the fact that intonationally marked topic-focus articulation gives rise to a non-accommodatable presupposition. Given an interpretational weak constraint: **Do Not Accommodate**, the use of topic-focus intonation where the presupposition is not resolvable loses out from other candidate generations that do not presuppose: they do not violate the accommodation constraint. And it is almost necessary to include the intonational variants in the candidate set which do not give rise to the presupposition.

The explanation uses an novel way of thinking about the application of optimality theory to the syntax and interpretation of natural languages. We have both interpretation constraints and generation constraints which are simultaneously applied to pairs of generations and interpretations. A pair $< g, i >$ can be suboptimal even if the interpretation is an optimal interpretation of the input, because there is a g_1 that can be interpreted with less violations of the interpretation constraints. (Similarly a generation g can be optimal for the interpretation i by the generation principles but fail because there is a better interpretation i_1 than the intended i available for g.)

I use *Blutner's Theorem* for the general principle: if a trigger context has simple non-triggering expression alternatives with the same meaning, it does not accommodate. The simplicity of the alternative expressions guarantees that they are considered in the optimality contest, so that Blutner's reasoning applies to

them. It is a strong principle and it is a rewarding game to try to refute it. The game is so rewarding that one is sometimes tempted to go to the weaker principle: **Obligatory Triggers Do Not Accommodate**. So far neither me nor Blutner nor anybody else have come up with a good OT reason why this should be so and it is fully unclear what could be the flaw in Blutner's reasoning. So I stick here to the full strength of Blutner's Theorem and use it to draw interesting conclusions about the semantics of the apparent counterexamples.

Unproblematic cases are the occurrences of presupposing particles. Here clearly one must take the view that the same context without them must be an alternative of the required simplicity. And this is largely borne out by the facts, though interestingly not entirely. E.g. in (12) we get instead of a free accommodation, in the absence of suitable antecedents, the inference that it is the speaker who wants coffee. Whether this is partial resolution based on the highly salient speaker or idiom, I do not want to discuss further here.

(12) Do you want coffee too?

More problematic is the case of knowledge and belief. It seems belief provides knowledge with a simple non-presupposing expression alternative, but knowledge accommodates rather well. I have to follow here the opinion of most theorists of knowledge that it is simply false to claim that knowledge equals truth plus belief. Geurts (p.c.) has proposed *manage* as a counterexample, but all that we have to deny is that its semantical contribution is exhausted by the presupposition of the difficulty of the action expressed in its complement: apparently this is also part of what it says.

The most interesting counterexample is provided by the opposition between $a(n)$ and *the*. There are uses of *the* that easily accommodate, like: *the inventor of electrical power* and there are cases that follow Blutner's theorem in being nearly unaccommodatable, as in (13).

(13) The man told me that he was going to get angry

The choice for a definite description is more complex than just the choice between a presupposing and a non-presupposing article. (See the full paper). We may perhaps say that all definite descriptions are presupposing, but they are only accommodatable when they are unique descriptions. The combination of the definite article with a non-unique description is a trigger that has the indefinite article as a simple expression alternative. The combination of the definite article with a unique description does not have the definite article as a simple expression alternative, because, then, it is obligatory to choose the definite article.

The epistemics of presupposition

Anthony S. Gillies
University of Arizona

Abstract

Successful linguistic interaction requires agents to agents to be able to reason about what is being said. Given this, it is natural to pursue the extent to which general epistemic principles can be brought to bear on semantic phenomena. In particular, I look at the interaction between the dynamics of belief and presupposition. A simple defeasible update semantics for presupposition is given in which accommodation is understood as belief updating, and presupposition failure as failed belief revision.

1 Introduction: Why epistemology matters

What is formal semantics a theory of? At least one plausible requirement is that our semantic theories had better mesh with the natural language inferences we routinely make. But surely these inferences depend on how we assimilate and use partial information in a dynamic world. In short, these inferences depend as much on our general epistemic architecture as they do on our semantic competence. So epistemology matters to formal semantics.

The dependence goes the other way, too: formal semantics matters to epistemology as well. A healthy amount of our justified beliefs are grounded by testimonial reports of others. I have never been to Argentina, but I have a lot of justified beliefs about it due to things people who have been there have told me about it. The particulars of my beliefs about Argentina thus depend in an essential way on successful semantic interpretation. If what we are interested in is a general theory of information exchange—a theory for how agents can exchange and use information about the world—then the line separating epistemic concerns from semantic concerns is bound to get blurry.

I want to push one way of blurring this line. In particular, I want to explore the interaction between general epistemological considerations and presupposition. Consider the notion of when an utterance ϕ which presupposes ψ can be uttered. Suppose that ψ is an object of mutual belief between us. Then I can easily assert ϕ. On the other hand, if I know that you believe $\neg\psi$, then I cannot merely assert ϕ and expect our conversation to go along smoothly. Likewise, from the hearer's point of view. Upon hearing ϕ (with presupposition ψ) intuitively all that is required is that ψ meshes well with the other things I believe. Notice that all of this is quite independent of the issue of whether ψ is *true*. The crucial question, most of the time, is whether what is presupposed is a *justified* belief. My main focus here will be the belief updates of a hearer which are induced by presuppositions.

2 Defeasible reasons and default logic

Some reasons are more stable than others. Perfectly stable reasons—*conclusive* reasons—entail their conclusions. More frequently we have less stable reasons for holding beliefs which are nonetheless justified: these are *defeasible* reasons. Defeasible reasons create a presumption in favor of their conclusions, but this presumption can be defeated. Defeat comes in two flavors. A *rebutting defeater* for a reason for ϕ is any reason for $\neg\phi$. An *undercutting defeater* for a reason from ψ to ϕ is any reason for denying the connection between ψ and ϕ. Rebutting defeaters are roughly the normal defaults from Reiter (1980). Undercutting defeaters are similar to what Veltman (1996) calls non-accidental exceptions.[1]

Some reasons are also stronger than others. Conclusive reasons, of course, the strongest possible reasons. But even among defeasible reasons there are differences in strength to be found. Suppose I believe ϕ (defeasibly). Then suppose I encounter the rebutting defeater $\neg\phi$. The latter consideration defeats the former only if my reasons for it are strictly stronger than my reasons for the former. If my reason for ϕ is strictly stronger than my reason for $\neg\phi$, then I should disregard the would-be defeater. If my reasons for ϕ and $\neg\phi$ are of equal strength, then it seems clear that I should retract my belief in ϕ but I should *not* admit $\neg\phi$ into my set of beliefs. This is a case of *collective defeat* (Pollock , 1995). Certain facts about presupposition accommodation can be seen as a special case of these general facts about reason strength. Before turning back to presupposition, I will first sketch a basic framework for defeasible reasoning.

Default logic (Reiter , 1980) provides one framework in which to investigate the structure of defeasible reasoning. The core idea of default logic is quite simple: defeasible reasoning is the result of combining partial information about the world with a set of rules for plausible inference (i.e., defaults). Let $\mathcal{L}_0$ be a classical propositional language with a set $\mathcal{A}$ of atomic formulas, and logical connectives $\neg$ and $\wedge$. Let W be the set of partial functions from $\mathcal{A}$ to truth-values. Elements of W are like partial possible worlds, and so represent partial information about the world.

Defaults have the form $\alpha : \Diamond\beta/\gamma$, where $\alpha, \beta, \gamma \in \mathcal{L}_0$. The intended interpretation of such a default is something like "If you believe α and it is consistent to also believe β, then go ahead and conclude γ." Let D be any set of defaults. To model reason strength, we can impose a partial order *preceq* over D. A *default theory* is a pair $(w, D^{\preceq})$. Extensions of a default theory prescribe the limits to what an agent can believe.

Definition 1 (Extensions) *Let $\Delta = (w, D^{\preceq})$ be a default theory. E is an extension of Δ iff E is a minimal set such that:*

- *$w \subseteq E$;*
- *E is closed under classical consequence; and*
- *E is faithful to all the defaults in D.*

[1] Pollock (1995) thoroughly explores the logic of undercutting defeat.

If $d = \alpha : \Diamond\beta/\gamma$ is in D, then E is faithful to d just in case if $\alpha \in E$ and $\neg beta \notin E$ then $\gamma \in E$.

3 Defeasible updating and presupposition

Update semantics (US) has been fruitfully applied default reasoning in Veltman (1996). There are a number of features of Veltman's approach, however, that are at odds with some facts about human epistemology. One is that reason strength seems to matter. Reason strength seems to matter to presupposition also. Suppose, out of the blue, you say to me

The King of France is bald (1)

This is just classic presupposition failure. But suppose you first explain to me that you have been doing some sleuthing, and found out that there is a Royal family still in France—living underground, or what have you. Then, when you say (1), I accommodate the presupposition. Why? Because you have just given me a reason of sufficient strength to defeat my earlier belief that there is no King of France. The fact that a statement presupposes another is *ipso facto* a reason for believing the latter.

To implement this idea, we need a mechanism for representing varying strengths in the framework of US. Instead of using the mechanisms for updating with defaults that Veltman explores, I propose that we use a propositional default logic like the one I sketched earlier.[2] Let $w_1, \ldots, w_n$ be the elements of W (the set of partial possible worlds) and let D be a set of defaults. Each of $(w_1, D), \ldots, (w_n, D)$ is a default theory. We can use extensions of these to play the role of possibilities in an update semantics. To do that, we have to augment Definition 1 to reflect the strengths of (possibly competing) defaults.

Definition 2 (Extensions, again) *Let $\Delta_i = (w_i, D^{\preceq})$ be a default theory with extensions E and E'. The possibility based on Δ_i is the $\preceq$-maximal of $\{E, E'\}$ if it is unique, and $\bigcap\{E, E'\}$ otherwise.*

With this change, we can give a standard definition (plus or minus a bit) for the set of possibilities and information states for an update semantics.

Definition 3 (Possibilities) *Let (W, D) be as before. The set I of possibilities based on (W, D) is the set of extensions of the default theories $(w_1, D), \ldots, (w_n, D)$, modulo Definition 2.*

Information states, as usual, are subsets of I.

Definition 4 *The set S of information states is the smallest set such that $s \in S$ iff $s \subseteq I$.*

[2] Default logic is in one sense less elegant that Veltman's system. But default logic is a bit simpler, which makes it easier to see what's going on.

Before turning to the semantics, we need to extend the expressive power of the basic language to have a rudimentary presupposition logic (Beaver , 1991). Let $\mathcal{L}_1$ be the smallest set such that:

- $\mathcal{L}_0 \subset \mathcal{L}_1$
- If $\phi \in \mathcal{L}_0$, then $\partial\phi \in \mathcal{L}_1$

Intuitively, $\partial\phi$ means that ϕ is presupposed material.[3]

For a fixed set of defaults, the interpretation function for Defeasible Update Semantics (with presuppositions), $[\cdot]_{DUS}$, is a partial function from information states to information states.

Definition 5 (Interpretation in DUS) *Fix a set D of defaults. Let s be any information state based on (W, D), and ϕ, ψ be any well-formed formulae of $\mathcal{L}_0$. $[\cdot]_{DUS}$ is given recursively by:*

- $s[p] = \{i \in s | p \in i\}$
- $s[\neg\phi] = s \setminus s[\phi]$
- $s[\phi \wedge \psi] = s[\phi][\psi]$
- $s[\partial\phi] = s$ *if* $s[\phi] = s$ *and undefined otherwise.*

So far, there is nothing that distinguishes DUS from other update semantics for presuppositions.

Intuitively, accommodation seems a little like a repair strategy for a conversation after presupposition failure (Lewis , 1979). On the other hand, it does not seem radically different from the process of interpretation. Can we have it both ways? Accommodation can be nicely embedded into DUS, and this is the chief virtue of this approach. Accommodation is a default rule (schema):

Accommodation Default $\partial\phi : \Diamond\phi/\phi$

Since information states are built from applying defaults, updating is already sensitive to the defeasible consequences of incomplete world pictures. By adding the accommodation default, we have merely added one more way that an incomplete picture of things can be plausibly extended.

Finally, I want to return to the issue of reason strength. DUS was motivated in part by the need to recognize reason strengths in presupposition. Suppose we have two defaults in D: the accommodation default, and a "no Queen" default—assume that a country does not have a Queen if it is consistent to do so. Suppose we do not know whether or not Australia has a Queen. Now consider the sentence

The Australian voters have decided to keep their Queen. (2)

[3]The unary decoration for presupposition and the binary relation ϕ_ψ for "ϕ presupposes ψ are of course interdefinable.

This presupposes that Australia has a Queen. If we impose no ordering on D (or if the two defaults have equal strength), we have a case of collective defeat when we try to update with (2). This is *total failure*. If the "no Queen" default is stronger, then updating with (2) also results in total failure. But notice what happens if the accommodation default is strictly stronger than the no Queen default: interpretation proceeds like we would expect even though what is presupposed is strictly speaking *new material*.

4 Conclusion

I have tried to suggest one way that general epistemic concerns and issues in formal semantics proper can be fruitfully combined. Along the way we have been able to generalize the notion of information state by basing them upon extensions from default theories. By doing things this way accommodation can be though of as *both* a repair strategy (in the sense that it extends what is known for sure) and keep its formulation of a piece with the rest of the semantics.

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Constructional Ambiguity in Conversation[1]

Jonathan Ginzburg
King's College, London
Hebrew University of Jerusalem

Ivan A. Sag
Stanford University

Abstract

The paper considers the contents associated with clauses in conversational interaction, focussing particularly on the issue of how grammatical frameworks can accommodate uses such as intonation questions and reprise uses. We point out that the phenomena at issue are problematic for views of the syntax/semantics interface such as radical lexicalism and syntactic modularity . We describe a grammatical system formulated within HPSG in which generalizations about phrasal types, characterized by means of constraints on both the syntactic and semantic components of the sign, are captured by means of multiple inheritance hierarchies. We show how this system can accommodate the relevant phenomena.

1 Introduction

Although declaratives are standardly assumed to denote propositions, conversational interaction reveals the existence of additional contents. Thus, a declarative such as (1a) is (at least) 4 ways ambiguous: for a start, in addition to the propositional reading, it has a reading as a regular information question. Although this different use has often been assumed to be one of illocutionary force (see e.g. Vanderveken 1990), as soon as one accepts the overwhelming arguments for distinguishing polar questions from propositions (see e.g. Groenendijk and Stokhof 1996), these apply equally here. In addition to these two readings, two more exist for (1a). These arise when (1a) is used as a *reprise* to clarify a prior use of (1a) expressing a proposition or a question. That the contents of these reprises is distinct from (1b) or (1c) is fairly straightforward to demonstrate — the repriser is asking a question which concerns the previous utterance, not the political situation, nor is (s)he asserting a proposition. The paraphrase we propose for such utterances is in (1d,e). Similar ambiguities occur with interrogative clauses, as illustrated below.

(1a) A: **The political situation is desperate**
(1b) the proposition p **that the political situation is desperate**;
(1c) the question **whether p**.
(1d) (Context: B has uttered (1a); A repeats the utterance.)
Content: **Is B claiming that the political situation is desperate?**
(1e) (B has uttered (1a) with rising intonatation and attempted to convey (1c).
A repeats the utterance for clarification purposes.)
Content: **Is B asking whether the political situation is desperate?**

Providing a descriptively and explanatorily adequate account of such ambiguities for clauses poses an interesting challenge for existing views of the interface between

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syntax and semantics. Such ambiguities have been ignored in most accounts of sentential meaning, although some researchers have suggested that that they fall outside the domain of grammar (see references below). In this paper, we rebut such claims. We suggest that capturing such ambiguities poses a particularly tough challenge for certain lexicalist frameworks, e.g. highly lexicalized versions of HPSG and categorial grammar (e.g. Morrill 1994, Steedman 1996), which have yet to address the issue of how lexically specified types and general combinatory principles can be restricted to achieve construction-specific effects. Furthermore, we argue that these ambiguities present intrinsic difficulties for any purely modular syntax/semantics interface such as that assumed in much transformational work, where the input to semantics is a scopally disambiguated form ('logical form') whose derivation takes place independently of any contextual information (see e.g. May 1985, Chomsky 1995). The paper describes a grammatical system formulated within HPSG in which generalizations about phrasal types, characterized via constraints on the syntactic, semantic and contextual components of the sign, are captured by means of multiple inheritance hierarchies. The system offers a simple and comprehensive account of the variations in clausal meaning illustrated in (1).

2 Reprise and Non-reprise uses of *Wh*-phrases

We start by considering reprise uses. These have received short shrift in much recent literature. Either they are dismissed summarily as 'metalinguistic' and not genuine questions (see Cooper 1983, Janda 1985, and Engdahl 1986) or else they are assumed to involve an object of a different semantic type — Comorowski (1989,1994) follows Karttunen (1977) in suggesting that reprise questions denote a property of a property of a proposition. Our basic claim is that reprise uses are metalinguistic only in that the CONTENT that they give rise to contains as a constituent the illocutionary force of the utterance that it reprises. Beyond that, as we will show, there is nothing going on — syntactically or semantically — that is fundamentally different from other uses of interrogative clauses.

As shown by Comorowski (1989), most of the SYNTACTIC constraints on dislocation of interrogative phrases (including the Coordinate Structure, Complex-NP, and Unit-Movement constraints) also apply to reprise uses — forms violating these constraints cannot be used for 'regular' uses, NOR CAN THEY BE USED TO REPRISE. An important set of data for our claim is that reprise sentences can be paraphrased and disquoted by ordinary uses of entirely 'normal' fronted interrogative sentences:

(2a) A: **You like** WHO**?** paraphrase: **Who did you say (just now) that you like?**
(2b) (Context: B: **Go home, Bo!)** A: **Go** WHERE**?**
paraphrase: **Where did you order me (just now) to go?**
(2c) **Who likes** WHICH MOVIE**?**
paraphrase: **(?)Which movie did you (just now) ask me who likes?**
(2d) Tracy: **You like** WHO**?** paraphrase: **Tracy was amazed at what I told her, so she asked me who it was that I had said I liked.**

We thus propose that the content of a sentence S_0 used to reprise a sentence S can be specified as follows: it is a question whose associated open proposition has n ($n \geq 0$) variables. The main relation of the open proposition is an illocutionary relation (*assert*, *ask*, *order*), which has two arguments: an utterer, filled by the individual whose turn immediately preceded the current speaker, and a message-arg, filled by a semantic object appropriate for the illocutionary relation. Moreover, the question presupposes a tight matching between S and S_0's message-arg, namely that the former is an instantiation of the indices of the latter. With this in mind, we can now observe an ambiguity that occurs in interrogatives akin to that observed for declaratives above. Despite a long-standing assumption to the contrary in most generative

work (English putatively contrasting with Chinese following Huang 1982), English DOES allow for non-reprise unary in-situ *wh*-interrogatives, as exemplified in (3a) below. A paraphrase such as (3b), which we argue to be applicable to reprise uses, is clearly not what (3a) means. An important contrast between reprise and non-reprise uses of in-situ *wh*-phrases is that the latter can either occur in the presence of a dislocated *wh*-phrase, or else, in the absence of any such phrase, it must be assigned widest scope within a matrix declarative clause:

(3a) (Context: B: I'm sending the croissants to Barringers and the sourdough to Florentin.)
A: and the bagels you're going to send where?
(3b) Where did you say you will send the bagels to?
(4a) Bill assumes (that)/*wonders Jill met who?
(4b) Bill wonders who exactly knows that Jill met who.
(4c) Give who the book? (can be used ONLY to reprise.)
(4d) Do I like who? (can be used ONLY to reprise.)

3 An HPSG Account

We follow Sag (1997) in expressing generalizations about the shared properties of diverse types of phrases, by classifying phrases not only in terms of their 'xbar' type (e.g. whether they are headed or not; if they are headed, what kind of daughters are involved, etc.), but also in terms of a further informational dimension of clausality. Thus, each maximal phrasal type inherits both from a CLAUSALITY type and from a HEADEDNESS type. This classification allows us not only to recognize a distinction between clauses and nonclauses, but also to identify at least the following subtypes of the type *clause*: *decl(arative)-cl(ause)*, *inter(rogative)-cl(ause)*, *imp(erative)-cl(ause)*, *excl(amative)-cl(ause)*, *core-cl(ause)* and *rel(ative)-cl(ause)*. For purposes of this abstract, we discuss only *decl-cl* and *inter-cl*, which are specified as in (5a,b). The effect of this specification is to establish a conventional correlation, plausibly universal in nature, between clausal construction types and types of content, which we analyze using a situation theoretic ontology based on Ginzburg 1995a,b. Questions are treated in terms of feature structures like (5c), where the components are a set of PARAMETERS and a (parametric) proposition; the PARAMS set is empty for a polar question and non-empty for a *wh*-question. This approach to questions presupposes a non-quantificational view of *wh*-phrase meaning (see, for example, Berman 1991, Ginzburg 1992.). We posit a type of clause — *headed-int-cl* — that is superordinate to most types of interrogative (see (5d)); The exceptions ignored here are elliptical sluiced clauses, which we assume to be unheaded.).

(5a) *decl-cl*:

$$\left[\text{CONT}\ \left[\begin{matrix}\textit{proposition}\\ \text{SOA}\ \boxed{1}\end{matrix}\right]\right] \rightarrow \ldots\ \text{H}\left[\begin{matrix}\text{VFORM}\ \textit{fin}\\ \text{CONT}\ \boxed{1}\end{matrix}\right]\ldots$$

(5b) *inter-cl*:

$$\left[\begin{matrix}\text{VFORM}\ \textit{(in)fin}\\ \text{CONT}\ \textit{question}\end{matrix}\right] \rightarrow \ldots$$

(5c)

$$\left[\begin{matrix}\textit{question}\\ \text{PARAMS}\ \{\pi, \ldots\}\\ \text{PROP}\ \left[\begin{matrix}\textit{proposition}\\ \text{SIT}\ s\\ \text{SOA}\ \textit{soa}\end{matrix}\right]\end{matrix}\right]$$

(5d) *hd-int-cl*

canon-int-cl *is-int-cl*

pol-int-cl wh-int-cl repr-int-cl dir-is-cl

The type *headed-int-cl* is characterized by the requirement that all its subtypes satisfy the *Wh*-Retrieval Principle (WHRP) given in (6). This requires that the STORE value of a *hd-int-cl* be the head daughter's STORE value, minus some set of parameters that are included in the clause's PARAMS set. Note that we intentionally allow the set of retrieved parameters to be the empty set, a move whose consequences will be apparent below. The WHRP is the sole mechanism we assume for interpreting *wh*-phrases, whether dislocated or in situ.

(6) *Wh*-Retrieval Principle (WHRP):
hd-int-cl:

$$\left[\begin{array}{ll}\text{STORE} & \boxed{1} \dot{-} \boxed{2} \\ \text{CONT} & \left[\text{PARAMS} \quad \boxed{2}\right]\end{array}\right] \rightarrow \ \ldots \ \text{H}\left[\text{STORE} \quad \boxed{1}\right] \ \ldots$$

For reasons of space we omit discussion of *wh-int-cl* and *pol-int-cl*, used to generate the familiar extracted *wh*-interrogatives and matrix polar interrogatives of English. Common to all in-situ constructions is the fact that they are headed by a finite indicative verb and cannot occur as the complement of an embedding predicate. A constraint capturing this characterizes *is-int-cl* — also a subtype of *hd-only-ph* (a non-branching headed phrasal type). The constraint characterizing *repr-int-cl* is given in (7). It is used to analyze reprises by building a reprise content (as specified above) through identification of the content of the head daughter with that of the msg-argument of the open proposition, as well as the introduction of the requisite presuppositions:

(7) *repr-int-cl*:

$$\left[\begin{array}{ll}\text{CONT|PROP|SOA} & \left[\begin{array}{ll}\text{QUANTS} & \langle\ \rangle \\ \text{NUCL} & \left[\begin{array}{ll}\textit{illoc-rel} & \\ \text{UTTERER} & i \\ \text{MSG-ARG} & \boxed{2}\end{array}\right]\end{array}\right] \\ \text{CONX} & \left\{\begin{array}{l}\textit{prev-spkr}(i),\ \textit{prev-utt}(\boxed{3}), \\ \textit{subst-inst}(\boxed{3},\boxed{2})\end{array}\right\}\end{array}\right] \rightarrow \ \text{H}\left[\text{CONT} \quad \boxed{2}\right]$$

Thus, to interpret a reprise use of *Who saw WHAT?*, one constructs a interrogative of type *wh-int-cl* with the parameter corresponding to *WHAT* remaining in storage. This phrase serves as the head daughter from which the reprise clause is built, the parameter being retrieved using WHRP. Hence, a content emerges corresponding to the content that would be assigned to a non-reprise extraction, including interrogative *What did you ask who left?* (if this were grammatical):

(8)

S

$$\left[\begin{array}{ll}\textit{repr-int-cl} & \\ \text{STORE} & \{\ \} \\ \text{CONT} & \left[\begin{array}{ll}\textit{question} & \\ \text{PARAMS} & \{\pi_k\} \\ \text{PROP|SOA|NUCL} & \left[\begin{array}{ll}\textit{ask-rel} & \\ \text{UTTERER} & i \\ \text{MSG-ARG} & \boxed{2}\end{array}\right]\end{array}\right] \\ \text{CONX} & \left\{\begin{array}{l}\textit{prev-spkr}(i),\ \textit{prev-utt}(\boxed{3}), \\ \textit{subst-inst}(\boxed{3},\boxed{2})\end{array}\right\}\end{array}\right]$$

S

$$\left[\begin{array}{ll}\textit{wh-int-cl} & \\ \text{STORE} & \{\pi_k\} \\ \text{CONT} & \boxed{2}\left[\begin{array}{ll}\textit{question} & \\ \text{PARAMS} & \{\pi_j\} \\ \text{PROP|SOA} & \left[\begin{array}{ll}\text{NUCL} & \left[\begin{array}{ll}\textit{see-rel} & \\ \text{SEER} & j \\ \text{SEEN} & k\end{array}\right] \\ \text{RESTR} & \{\textit{person-rel}\ (j)\}\end{array}\right]\end{array}\right]\end{array}\right]$$

NP_j 'S'

$$\left[\text{STORE} \quad \{\pi_j\}\right] \qquad \left[\text{STORE} \quad \{\pi_j, \pi_k\}\right]$$

V NP_k

$$\left[\text{STORE} \quad \{\pi_j, \pi_k\}\right] \qquad \left[\text{STORE} \quad \{\pi_k\}\right]$$

Who saw WHAT

The type *dir-is-cl* is used to generate non-reprise in-situ constructions. The only constraint on this type which does not arise by inheritance is that the open proposition of the question content is identified with the content of the head daughter, which is hence required to be propositional. Thus (9) predicts without further ado facts such as the non-reprise interpretation of examples like (3a) and (4a) above and the impossibility of a non-reprise reading for (4c,d).

(9) *dir-is-cl*:

$$\left[\text{SS|LOC|CONT|PROP} \quad \boxed{1}\right] \rightarrow \ \text{H}\left[\text{CONT} \quad \boxed{1}\right]$$

Finally, let us return to the examples in (1). The regular propositional reading is analyzed as a proposition–denoting *decl-head-subject-clause* (roughly, the familiar 'S → NP VP' ¿sentential rule.). The 'intonation question' reading arises by taking the just mentioned *decl-hs-cl* as the head daughter of a *dir-is-cl*. Utilizing vacuous parameter retrieval, a polar question reading arises, as illustrated in (10). Using *decl-hs-cl* as the head daughter in a *repr-int-cl* with vacuous parameter retrieval results in the reading (1d). Whereas, using *dir-is-cl* as the head daughter in a *repr-int-cl* schema, in this case the clause in (10), yields (1e), schematically diagrammed in (11).

(10)

S

$$\left[\begin{array}{ll}\textit{dir-is-cl} & \\ \text{STORE} & \{\ \} \\ \text{CONT} & \left[\begin{array}{ll}\textit{question} & \\ \text{PARAMS} & \{\ \} \\ \text{PROP} & \boxed{2}\end{array}\right]\end{array}\right]$$

S

$$\left[\begin{array}{ll}\textit{decl-hs-cl} & \\ \text{STORE} & \{\ \} \\ \text{CONT} & \boxed{2}\left[\begin{array}{ll}\textit{proposition} & \\ \text{SOA} & \left[\begin{array}{ll}\text{QUANTS} & \left\langle\left[\begin{array}{ll}\textit{the-rel} & \\ \text{INDEX} & j \\ \text{RESTR} & \{\textit{political-situation}(j)\}\end{array}\right]\right\rangle \\ \text{NUCL} & \left[\begin{array}{ll}\textit{desperate-rel} & \\ \text{INSTANCE} & j\end{array}\right]\end{array}\right]\end{array}\right]\end{array}\right]$$

NP_j VP

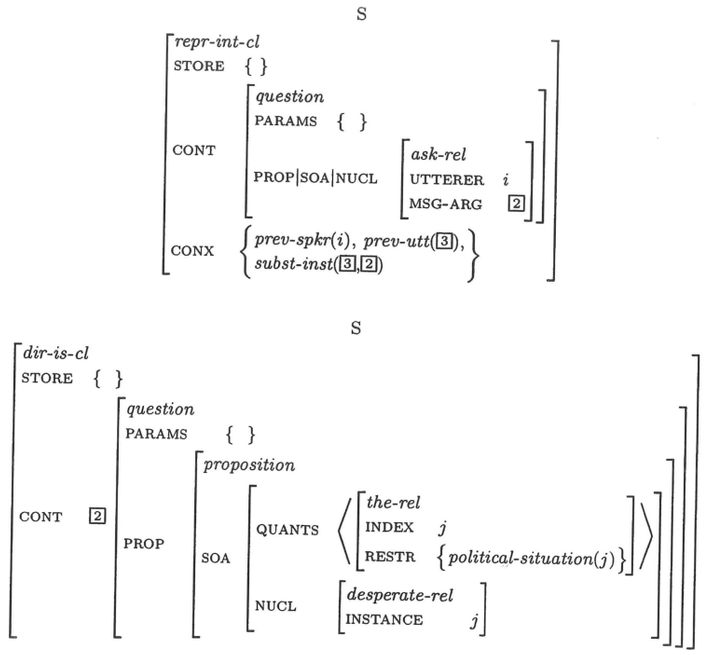
$$\left[\text{STORE} \quad \{\ \}\right]$$

V AP

$$\left[\text{STORE} \quad \{\ \}\right] \qquad \left[\text{STORE} \quad \{\ \}\right]$$

The political situation is desperate

(11)



The political situation is desperate

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Binding by implicit arguments.

Alice G. B. ter Meulen
University of Groningen, NL

Abstract

Pronouns require overtly asserted antecedents, but anaphoric definite descriptions do not. A game-theoretic account of anaphoric definite descriptions is presented where the antecedent is an implicit existential argument of a predicate in a preceding sentence, whose referent must be inferred. Verifier's claim that he has a verifying strategy for this inferred existential statement explains why pronouns cannot be bound by implicit arguments, until the Falsifier demands execution of that claimed verifying strategy. It is discussed how DRT, as representational dynamic semantics, and DPL, as compositional dynamic semantics, could differentiate between asserted, inferred and presupposed indefinites to account for these differences in their dynamic binding potential. Implicit arguments are linguistically economical as they avoid scope-disambiguation, force the inferred existential to remain in focus, and constrain the accommodation of presuppositions.

1. The issue.

Partee's well-known marbles-argument was originally intended to show that truth-conditionally equivalent statements may differ in dynamic binding potential (1a, b).

(1) a. Nine of the ten marbles are in the bag. #It is under the sofa.
b. One of the ten marbles is not in the bag. It is under the sofa.

Pronouns require overtly asserted antecedents and do not allow antecedents to be derived by bridging inferences, as opposed to definite descriptions which presuppose the indefinite NP, entailed by bridging inference from the prior discourse (2).

(2) Nine of the ten marbles are in the bag. The missing marble is under the sofa.

The discourse in (2) is coherent, as the presupposition (3c) of the definite description *the missing marble* corefers with an entailed NP in (3b) of the prior asserted sentence (3a).

(3) a. Nine of the ten marbles are in the bag.
c. One of the ten marbles is not in the bag.
d. A marble is missing.
e. It is under the sofa.

Presupposed indefinites carry a weak familiarity requirement that may allow them to be resolved by matching NPs in the entailments of the prior discourse, if there is no asserted antecedent (cf. Van der Sandt, Rob (1992)). As last resort, presupposed indefinites get accommodated globally in case neither an inferred antecedent nor an asserted one is available, overruling their weak familiarity requirement.
The issue addressed in this paper is why the discourse in (1a) cannot be reconstructed in a similar way by adding an entailment of the first sentence containing an antecedent for the pronoun, analogous to (3) spelling out the coreference chain in (2). If (3b) were not inferred, but asserted, of course the discourse consisting of three asserted clauses (3a) + (3b) + (3d) would be perfectly coherent. Insight is needed into the difference in dynamic binding potential of asserted, inferred and presupposed indefinites.

2. Implicit arguments as antecedents.

Related to this difference in antecedents for pronouns versus definite descriptions is the fact that implicit arguments, e.g. agent-less resultatives as in (4), may serve as antecedents for definite descriptions, but again not for pronouns, as they are not asserted.

(4) a. John got his hair cut. The barber used a razorblade.
b. John got his hair cut. #He used a razorblade.

Implicit arguments are not derived by bridging inferences, as they must already in some sense be present in the predicate's argument structure, but receive no overt expression. From the first sentence in (4a) we infer that someone, other than John, cut John's hair, but this inferred indefinite NP cannot serve as antecedent for the pronoun in (4b), though again it can corefer with the presupposition of the definite description *the barber* in (4a).
Any system of dynamic interpretation must explain why the active form (5a), readily inferred from the first sentence in (4a, b), with an existentially quantified overt agent is apparently unable to bind pronouns in discourse, but does resolve the existential presupposition of the definite description (5b).

(5) a. Someone cut John's hair.
b. The barber who cut John's hair used a razorblade.

If inferred indefinite NPs are supposedly static, they do not simply update the information state like asserted indefinites do, which introduce new discourse referents. Inferred indefinites do, however, introduce a reference marker with which the existential presupposition of a definite description may be resolved. Adding appositive relative clauses to pronouns as in (6) does seem to create

coherent discourse, at least with an appropriate prosodic contour of H*LL% on its subject NP.

(6) John got his hair cut. He who cut John's hair, used a razorblade.

This calls for a refined account of the differences in anaphoric potential of asserted, inferred and presupposed indefinites, constraints on the accommodation of presuppositions and the effects of high pitch pronouns, providing new insights into the information structure in natural language.

2. A game-theoretical account of implicit arguments.

In game-theoretical semantics implicit arguments are not to be interpreted by a move where the Verifier picks a referent, as ordinary asserted indefinite NPs would be. Instead, the Verifier should claim that he has a winning strategy in which he can pick a suitable referent no matter how the ensuing game may develop. The Falsifier is accordingly entitled to call upon the Verifier at any later point to play the game for the implicit argument and determine its referent. This kind of meta-move, to my knowledge not before used in GS for natural language, constitutes a significant extension of the power of the semantic interpretation, as it introduces an intensional dimension as well as indeterminacy into the moves. GS so extended is not any longer equivalent to a first order predicate logic. Of course, Verifier may indeed have a verifying referent at his disposal at the point where claims he does or at any later point, but he does not introduce it into the game as element in the common ground. Verifier may claim he is able to provide the referent, even when he does not or not yet know who it is, or, in the worst case, know there is none. The Falsifier is in a genuine imperfect information situation, as he cannot determine which of these three situations the game is in. He may decide to trust the Verifier and proceed with the game, or he may want to play it safe and call for the Verifier to execute the claim right away and provide the referent. What Falsifier should do is not determined by any linguistic input. It is Falsifier's own choice to proceed or to take the time to get Verifier to supply the referent of the implicit argument. This introduces indeterminacy into the GS rules and leaves room for notions such as trust, past experience or interpersonal skills to determine how to proceed with the game. It also means that the reversal of roles triggered by negation may burden players with prior commitments associated with the other role that they may not necessarily be able to act upon.
The game for the definite description in the second sentence makes the Verifier add its descriptive content to his previous claim that he is able to provide a suitable referent at any point, adding that Falsifier may try to pick another referent with the same properties (uniqueness condition). But a pronoun in the second could not be processed, unless the referent for the implicit argument is first provided. To interpret a pronoun in GS rules a referent must have been made available.
To illustrate the GS account of implicit arguments, consider the analysis of (4a) above. The play starts with Verifier picking a referent for the proper name 'John' and the referent for 'his hair'. He then claims that he has a winning

strategy for the game played by interpreting 'someone cut it', where the pronoun corefers with the NP 'his hair' already played. But Verifier does not play that game unless Falsifier demands it. The final step is relating the available referents by the predicate 'get' to a temporal reference point in the past of the speech time. The second sentence is played by Verifier adding the descriptive content of the definite description to his claim that he has a winning strategy for 'someone cut it', so that he now claims to have a winning strategy for 'someone cut it and he is a barber'. The remainder of the second sentence is played according to standard GS rules. This example will be presented in more detail in the talk.
If Falsifier wants Verifier to validate his claim and actually present the referent, the discourse may be continued with a coreferential pronoun. This would be equivalent to the coherent dialogue in (7), where A is the Verifier and B the Falsifier.

(7) A: John got his hair cut
B: Oh, who cut his hair?
A: Max did. He used a razor blade.

The idea that staking claims on winning strategies at certain points in the game adds a realistic flexibility to GS for Natural Language, as ordinary information exchanges often are too fast to take the time to reduce what is said to a purely extensional level where referents are picked and relations between them are established.

3. Implicit arguments in DPL and DRT

Other model-theoretic systems of dynamic semantics could also be adapted to offer explanations of binding by implicit arguments. Since in DPL all logical constants can be interpreted either statically or dynamically, inferred indefinites should be treated as static using only ordinary individual variables.
This would explain why (5a) is inferred from (4a), but lacks dynamic binding potential (4b). The resolution of definite descriptions 'activates' the static existential, identifying a newly introduced discourse variable for the presupposition with that static individual variable, creating the dynamic binding. The full paper presents more technical details, but also raises the question whether a compositional account may be given of implicit arguments. Alternatively, a DPL simulation of the claimed winning strategy in GS would be to ensure with a modality ranging over possible updates of the given information state, that every extension of the current assignment for (4a) could be extended to verify (5a). Resolving an anaphoric definite description would then amount to modal subordination.
In DRT implicit existential arguments cannot introduce an accessible reference marker, to avoid binding discourse pronouns. The inferred information should always introduce conditions in a separate DRS under a inference operator INF, interpreted epistemically as quantifying over all extensions of the given verifying embedding, to render these inferred reference markers inaccessible. Alternatively, inferred information could create an improper DRS, where an

undeclared reference marker is used in the conditions. Accommodating the presupposition would then amount to declaring the inferred reference marker and using it to bind the presupposition in the van der Sandt style accommodation. But this would certainly require fundamental modifications in the core concepts of the toolkit of (S)DRT.

4. The efficiency of implicit arguments

Implicit arguments are shown to promote efficient information-packaging, as they circumvent scope-disambiguation and constrain the accommodation of presuppositions. From (8a) we infer (8b), but not the active counterparts (8c, d), unless the assignment is already constrains the referent for the indefinite to a unique one, independent of the choice of student.

(8) a. Every student got his hair cut. The barber used a razorblade.
b. Every student's hair was cut by someone.
c. Someone cut every student's hair.
e. There was someone who cut every student's hair.

Existentially quantified implicit arguments reside within islands created by universal, i.e. left-decreasing NPs and provide inferred antecedents for definite descriptions in subsequent discourse. So (8a) may describe a situation where different barbers all used razorblades in cutting hair of different students. The definite description is hence not uniquely referring in an unrestricted domain, but the quantifier in the preceding sentence functions as restrictor of the domain within which the barber is the only barber, i.e. the restrictor of a sentence may continue to provide constraints on the domain of the next sentence in order to get definite descriptions to be locally uniquely referring. This connects to the issues of topic/focus differences in active and passive sentences which are considered beyond the scope of the current paper.
Right-decreasing subject NPs or negated VPs block the resolution of the definite description with the implicit argument, forcing the global accommodation of its presupposition (9).

(9) No student got his hair cut. The barber was on vacation.

In interpreting (9) there is no access to the inferred referent of 'someone who cut a student's hair (for each student)', as the negation creates a block to merging the definite description with it, even in the static domain. Hence the definite description provides a presupposition which is accommodated globally and only one barber is assumed to be on vacation. Implicit arguments are, like asserted indefinites, inaccessible within a negative nuclear scope, even for binding presuppositions of definite descriptions.

5. Conclusion

This paper is intended as a case study in the differences in binding potential of asserted, inferred and presupposed indefinites in dynamic semantics. As the current state of the art in the various toolkits of dynamic semantics have not yet taken such differences into account, they may require some adjustments in basic notions to account for the observations. As a subsidiary, but no less intended effect, this paper has tried to demonstrate that GS semantics provides a rather nice heuristically useful set of tools and concepts to help understand the interaction between verification and falsification of information exchanges, which probably can be transposed to other systems of dynamic semantics without too much difficulty.

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Modeling Ambiguity in a Multi-Agent System

Christof Monz

Institute for Logic, Language and Computation (ILLC)
University of Amsterdam

Abstract

This paper investigates the formal pragmatics of ambiguous expressions by modeling ambiguity in a multi-agent system. Such a framework allows us to give a more refined notion of the kind of information that is conveyed by ambiguous expressions. We analyze how ambiguity affects the knowledge of the dialog participants and, especially, what they know about each other after an ambiguous sentence has been uttered. The agents communicate with each other by means of a `tell`-function, whose application is constrained by an implementation of some of Grice's maxims. The information states of the multi-agent system itself are represented as a Kripke structures and `tell` is an update function on those structures. This framework enables us to distinguish between the information conveyed by ambiguous sentences vs. the information conveyed by disjunctions, and between semantic ambiguity vs. perceived ambiguity.

1 Introduction

The ambiguity of natural language poses problems for any formal theory within Linguistics, Philosophy, Cognitive Psychology or Artificial Intelligence. If one tries to set up a formal framework dealing with ambiguous expressions, one immediately faces interesting fundamental questions about the nature of ambiguity: How should the formal semantics of an ambiguous expression be defined? What is the information conveyed by ambiguous expressions? When is an expression perceived as ambiguous? The last question is relevant since speakers are often not aware of the fact that they have said something which is ambiguous.

These questions show that ambiguity mainly becomes relevant in situations where more than one person is involved. In this paper, we analyze when ambiguities arise by looking at a multi-agent system, where the agents also communicate with ambiguous statements. Analyzing ambiguity in a multi-agent system is promising since it allows us to create an artificial dialog situation where the environment is clearly defined and the issues mentioned above can be analyzed under sterile conditions.

Additionally, multi-agent systems are not only interesting as a tool for semanticists to formalize some pragmatic aspects. Existing multi-agent communication languages like KQML (Labrou and Finin 1994) and ACL (FIPA 1999) use some of Grice's *cooperative principles* (Grice 1989) to define the semantics of the agent language and make use of pragmatic notions stemming from speech act theory (cf. Searle 1969) to implement more complex forms of agent communication.

2 A Multi-Agent System with Ambiguity

The framework as it is proposed here, is to some extent similar to the contextual approach of Buvač (1996), who also uses a modal logic to formalize ambiguity. On the other hand, his approach is restricted to a single-agent scenario, and therefore not appropriate to answer the questions we mentioned in the preceding section.

2.1 The Framework

The scenario is very basic. Each member of a group of n agents knows some facts about the world and the other agents. The only action taking place, is that one of the agents tells a group of other agents what he knows. Is is assumed that he only tells things that he knows to be true and that the other agents do not doubt what he is saying. Two agents might differ in what they know, but for simplicity, it is assumed that their knowledge is non-conflicting.

To model the information state of the agents, we use valued rooted Kripke structures $(\mathfrak{M}, w, V)$: $\mathfrak{M} = \langle W, \{R_i\}_{i\in\mathcal{A}}, \mathcal{A}\rangle$, $w \in W$, and V is a valuation function, $V : W \to \mathbb{P}^2$, $\mathbb{P}^2$ being the powerset of the set of propositional variables $\mathbb{P}$. As usual, W is a set of possible worlds, $\mathcal{A}$ a finite set of Agents, and $\{R_i\}_{i\in\mathcal{A}}$ is a set of accessibility relations between worlds for each agent $i \in \mathcal{A}$. We say that wR_iw' if agent i considers world w' possible in world w. Knowledge is expressed by a set of modal operators $\{K_i\}_{i\in\mathcal{A}}$, where $(\mathfrak{M}, w) \models K_i\varphi$ iff $(\mathfrak{M}, w') \models \varphi$ for all w' such that wR_iw'. In the sequel, we sometimes omit the valuation: $(\mathfrak{M}, w) \models \varphi$ iff $(\mathfrak{M}, w, V) \models \varphi$, for arbitrary V.

Group knowledge (E) and common knowledge (C) are defined as in Fagin et al. (1995): $(\mathfrak{M}, w) \models E_G\varphi$ iff $(\mathfrak{M}, w) \models \bigwedge_{i\in G} K_i\varphi$ and $(\mathfrak{M}, w) \models C_G\varphi$ iff $(\mathfrak{M}, w) \models E_G(\varphi \wedge C_G\varphi)$. Information structures are fully introspective and serial; i.e., they are in KD45$_n$: For all $w \in W$ and $i \in \mathcal{A}$ it holds that

(D) $(\mathfrak{M}, w) \models \neg K_i\bot$ (seriality)

(4) $(\mathfrak{M}, w) \models K_i\varphi \to K_iK_i\varphi$ (positive introspection)

(5) $(\mathfrak{M}, w) \models \neg K_i\varphi \to K_i\neg K_i\varphi$ (negative introspection)

The agents are endowed with very limited communicative capabilities. In fact, the only communicative acts are of the form $\texttt{tell}(i, G, S)$, which is defined as follows:

Definition 1 (`tell`) `tell` is a function from valued rooted Kripke structures to valued rooted Kripke structures. It can be seen as an update function. Additionally, `tell` has three parameters, $(i, \{G\}, S)$, where i is an agent (the speaker), $G \subseteq \mathcal{A}\backslash\{i\}$ is a group of agents (the hearers),[1] and S is a natural language sentence belonging to some (not further specified) fragment $\mathcal{L}^{eng}$ of English.

Although being desirable, it is not possible in the proposed framework that two communicative acts take place at the same time. Allowing two or more `tell`-actions to take place at the same time, would require parallel updating. Again, for simplicity, we do not consider this possibility.

A function τ from $\mathcal{L}^{eng}$ to $\mathcal{L}^{\text{PL0}}$ (propositional logic) generates the possible semantic representations of S. Actually, $\tau(S)$ returns the set of equivalence classes of the readings, such that readings which are equivalent belong to the same class. $[\varphi]$ indicates the equivalence class φ belongs to.

Definition 2 (Semantic Ambiguity) If $S \in \mathcal{L}^{eng}$, then S is said to be semantically ambiguous iff $|\tau(S)| > 1$, i.e., there are at least two non-equivalent ways to represent the semantics of S.

The fact that s is semantically ambiguous does not mean that it is also *perceived* as ambiguous by the speaker or the hearer(s), cf. Poesio (1996). In Section 2.2, we will see how to define the difference between semantic and perceived ambiguity formally.

[1] The restriction that the speaker is not part of the group of hearers is mainly due to formal convenience, as it simplifies the implementation of some of the cooperative principles.

We are aware of the fact that propositional logic is not expressive enough to be an appropriate representation language for the semantics of natural language utterances, but this restriction allows us to blend out further intricacies that can arise in a multi-agent system for natural language dialogs (see, e.g., Francez and Berg 1994), so we can focus on issues that are strictly related to the problem of ambiguity.

2.2 Implementing Cooperative Principles

Before we discuss in more detail how ambiguity is treated, we pose some general constraints on the execution of communicative acts. These constraints are based on *Grice's maxims*, cf. Grice (1989), and can be considered as a partial implementation of Grice's maxims in a multi-agent system, see also Labrou and Finin (1994) and FIPA (1999) for different ways of integrating Grice's maxims into an agent communication language.

Definition 3 (Cooperative Principles) Given a valued rooted Kripke structure of the form $(\mathfrak{M}, w, V)$ representing the current information state, the following constraints are imposed on the application of `tell`. If $\texttt{tell}(i, G, S)(\mathfrak{M}, w, V) = (\mathfrak{M}', w', V')$, then $\exists[\varphi] \in \tau(S)$ such that

(i) $(\mathfrak{M}, w, V) \models K_i\varphi$
Maxim of Quality: *do not say that for which you lack adequate evidence.* This is implemented by requiring that a speaker knows that at least one of the readings of S is true.

(ii) $(\mathfrak{M}, w, V) \models K_i\neg C_{\{i\}\cup G}\varphi$
Maxim of Quantity: *make your contribution as informative as is required for the current purposes of the exchange.* Agent i knows that at least one reading of S is not part of the common knowledge.

(iii) $\forall[\psi] \in \tau(S)\backslash\{[\varphi]\}(\mathfrak{M}, w, V) \models K_i(C_{\{i\}\cup G}\psi \vee C_{\{i\}\cup G}\neg\psi)$
Maxim of Manner: *avoid ambiguity.* Agent i knows that it is common knowledge amongst the speaker and the hearers that either all readings ψ of S, such that $[\psi] \neq [\varphi]$, are true (and therefore uninformative) or false (an therefore conflicting).

(iv) $(\mathfrak{M}', w', V') \models C_{\{i\}\cup G}\varphi$
Grounding Criterion: After telling S, φ is common knowledge of the hearers and the speaker (i).

Similar to Labrou and Finin (1994), these conditions are divided into pre-conditions that have to hold before a communicative action can be executed (i.e., before updating the original Kripke model) and post-conditions that describe what has to hold afterwards.

(i)–(iii) are the pre-conditions of applying `tell` to a valued Kripke structure. (iv) is the post-condition, where the speaker's contribution is added to the common knowledge, see e.g. Clark and Schaefer (1992).

Updating in a multi-agent system where the pre-conditions (i)–(iii) are implemented as hard constraints will always yield a resulting state which satisfies the post-condition (iv). I.e., although the agents can communicate with semantically ambiguous sentences, it cannot happen that such a sentence is also perceived as ambiguous by the hearer(s).

On the other hand, if the pre-conditions (i)–(iii) are implemented as default constraints, and, for instance, the *Maxim of Manner* is violated by a speaker, the *Grounding Criterion* is not guaranteed to hold.

Definition 4 (Perceived Ambiguity) Let S be a semantically ambiguous sentence, as defined in Definition 2, $\texttt{tell}(i, G, S)(\mathfrak{M}, w, V) = (\mathfrak{M}', w', V')$, and the following conditions hold:

1. $(\mathfrak{M}', w', V') \models \neg C_{\{i\}\cup G}\varphi$
2. $(\mathfrak{M}', w', V') \models E_{\{i\}\cup G}(\bigvee_{[\varphi]\in\tau(S)} C_{\{i\}\cup G}\varphi)$

Then, we say that S is perceived as ambiguous.

Detection of ambiguity is also important for building intelligent dialog systems, because it can inform the system to apply repair strategies, cf. McRoy and Hirst (1995).

This illustrates also the difference between ambiguity and disjunction. If an ambiguous sentence S is treated the same way as the disjunction of its m readings $\bigvee_{k=1}^{m} \varphi_k$, it would result in a weaker post-condition of the form $(\mathfrak{M}', w', V') \models C_{\{i\}\cup G} \bigvee_{k=1}^{m} \varphi_k$.

Finally, we mention another important constraint on updating, namely the preservation of known facts.

Definition 5 (Information Increase) Let $\{K_i\}^*_{i\in\mathcal{A}}$ be the set of finite concatenations of elements of $\{K_i\}_{i\in\mathcal{A}}$, including the empty sequence ϵ. If $\vec{K} \in \{K_i\}^*_{i\in\mathcal{A}}$ and $(\mathfrak{M}, w, V) \models \vec{K}\varphi$, then $\texttt{tell}(i, G, S)(\mathfrak{M}, w, V) \models \vec{K}\varphi$.

This definition of information increase, which is a more general reformulation of Groeneveld's *descriptive information increase*, cf. Groeneveld (1995).

2.3 Updating with Ambiguous Information

Let us consider an example. The Kripke-structures depicted in Figure 1 and Figure 2, represent the information state of Agent 1 and Agent 2, respectively.[2] We restrict ourselves to two propositional variables p and q. Agent 1 does know that p holds, but is uncertain about the truth of q. In addition, he does not know whether Agent 2 knows p or q, or whether Agent 2 knows whether Agent 1 knows p or q, etc.

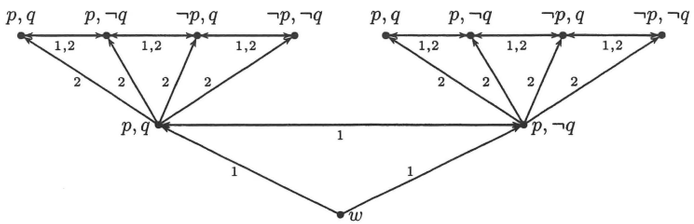

Figure 1: A Kripke model representing the information state of Agent 1

More formally, the following holds:

1. $(\mathfrak{M}, w, V) \models K_1 p \wedge \neg K_1 q$
2. $(\mathfrak{M}, w, V) \models \neg K_1 K_2 (C_{\{1,2\}} p \vee C_{\{1,2\}} q)$

Agent 2, on the other hand does know:

[2]Note that both figures belong to the same Kripke structure. The split-up is entirely due to space limitations.

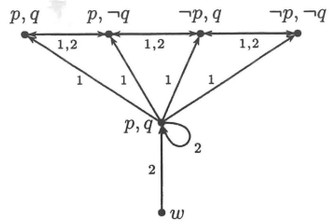

Figure 2: A Kripke model representing the information state of Agent 2

1. $(\mathfrak{M}, w, V) \models K_2(p \wedge q)$
2. $(\mathfrak{M}, w, V) \models \neg K_2(K_1 p \vee K_1 q)$

If Agent 1 tells Agent 2 that S is the case, where $\tau(S) = \{p, q\}$, then the model in Figure 1 and Figure 2 has to be updated with $\texttt{tell}(1, \{2\}, S)$. Again, focusing on the information state of Agent 1, this results in the Kripke-structures displayed by Figure 3 and Figure 4.

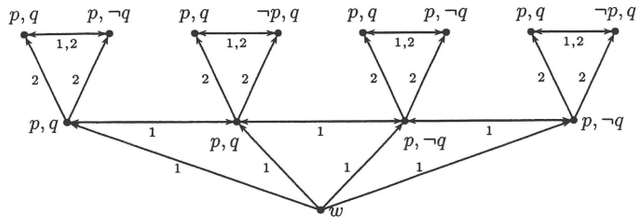

Figure 3: The information state of Agent 1 after updating with S

Having told S to Agent 2, Agent 1 knows that Agent 2 either knows that p holds or that he knows that q holds, i.e., $\texttt{tell}(1, \{2\}, S)(\mathfrak{M}, w, V) \models K_1(K_2 p \vee K_2 q)$.

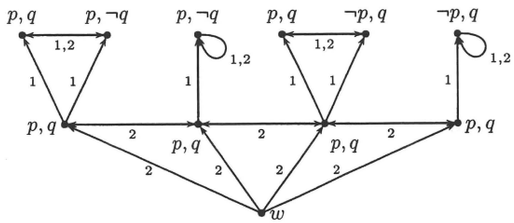

Figure 4: The information state of Agent 2 after updating with S

Determining the resulting information state of Agent 2 is a bit more complex. First of all, to which extent should Agent 2 obey the cooperative principles? We know that Agent 1 violated the maxim of manner, but Agent 1 does not know that. For simplicity, we assume that the hearer(s) give the speaker full credit, which means that they think that the speaker obeys all cooperative principles.

Turning to Figure 4, there are four possibilities, two for each reading of S. Either Agent 2 thinks that Agent 1 intended to say p, because he is uncertain about the

truth of q or because he knows that q is not true; and analogously for q, the other reading of S.

3 Conclusions

We have seen that, to some extent, ambiguity can be modeled in a multi-agent system. It became also clear that this is certainly a non-trivial task, involving a lot of intricacies, most of which we have simplified in this paper. The presented framework is mainly intended to give a rough idea how to formalize ambiguity in a multi-agent system, where several extensions are still needed. In particular, we intend to put future efforts into tackling two problems. How to extend the framework to first-order (dynamic) logic, and which other pragmatic principles can be implemented?

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Two approaches to modal interaction in discourse

C.F.M. Vermeulen
Departments of Philosophy and Linguistics
Utrecht University, the Netherlands[1]

Interaction between modalities

In this paper we are concerned with the formal semantics of modal interaction in discourse. Typical examples of modal interaction are cases of modal subordination, as in:

(1a) A lion might come in.
(1b) It would eat you first.
(1c) It might eat me later.

(2a) A lion might come in.
(2b) It might eat you first.
(2c) It might choose me instead.

The surface form of these examples reminds us of the following formulas: (1) $\Diamond p \wedge \Box q \wedge \Diamond r$; (2) $\Diamond p \wedge \Diamond q \wedge \Diamond r$. But a second look shows that the best approximation in ordinary modal logic of the meaning of the examples would be: (1) $\Diamond p \wedge (p \rightarrow \Box q) \wedge (p \wedge q \rightarrow \Diamond r)$; (2) $\Diamond p \wedge (p \rightarrow \Diamond q) \wedge (p \rightarrow \Diamond r)$. We see that 'below the surface' there is a lot of interaction between the modal expressions in discourse: the conditionalisations in the representations show that modalities are evaluated in context. The appropriate context is provided by previous modalities. In a standard modal representation language this causes a discrepancy between surface form and meaning that provides a serious challenge for formal, compositional semantics.
Intuitively the interaction of modal expressions seems to work as follows: each modal expression *selects* a context for its interpretation and *produces* a new context for the interpretation of modal expressions in subsequent discourse. Hence, modal expressions behave both like *anaphors* and like *antecedents*. (We find similar views in (1), (2), (3) and (5).) This intuitive account of the phenomena suggests that a formalisation in dynamic semantics is appropriate: after all dynamic semantics is motivated by the semantic interaction between distinct parts of discourse, in particular between antecedents and anaphors. Here we see that the interpretation of modal expressions involves a flow of information that is another striking example of discourse dynamics.
We discuss two ways of formalising the intuitive explanation, both in dynamic semantics. First we use a representation language with *indexed modalities*. We will give an *update semantics* for this language. Then we develop an alternative representation using a 'flat', string language. This language is interpreted in the algebraic style of (8). We will see that both ways of representing the interaction of modalities works for the examples. We generalise this initial comparison of the two approaches by giving a systematic way of translating the update language into the algebraic setting in such a way that meaning is preserved. The flat representation has the additional advantage of making the dynamics involved in the interpretation more explicit, thus providing, as it were, a *rational reconstruction* of the update functions.

Indexed modalities

First we investigate the representation of modal interaction in discourse by means of a language with index modalities. We extend a simple modal language by adding indices to the modalities. These indices indicate the interaction between modal expressions. A typical formula looks like: $\Diamond^i_j(\phi)$, where the subscript j indicates

[1]The research for this paper was supported by NWO, the Dutch Foundation for Scientific Research.

which context is selected and the superscript i shows which (new) context is introduced. This language obtains an *update style* interpretation (as in (4)): meanings of formulas are update functions on information states. Suitable information states are built from a set of possible worlds W. Each state is of the form $\langle I, V\rangle$, where $I \subseteq W$ is the *current/actual* state of information and $V : \text{IND} \to \text{POW}(W)$ assigns an alternative context of information to each of the indices $i \in \text{IND}$. The crucial clause of the update interpretation is as follows:

$$\langle I, V\rangle[\![\Diamond_j^i(\phi)]\!] = \begin{cases} \langle I, V'\rangle \text{ in case } (\langle V(j), V\rangle[\![\phi]\!])_0 \neq \emptyset \\ \langle \emptyset, V'\rangle \text{ otherwise} \end{cases}$$

Here V' differs from V at most on i and $V'(i) = (\langle V(j), V\rangle[\![\phi]\!])_0$. Thus a modal expression checks whether in $V(j)$ the formula ϕ can be processed succes.fully. If this is so, the result will be that $(\langle V(j), V\rangle[\![\phi]\!])_0$ (i.e., the first component of $\langle V(j), V\rangle[\![\phi]\!]$) is not empty. Note that we are testing in $V(j)$ and *not* the current state of information, I. But the formula does no only perform a test on $V(j)$, there is also some dynamics involved: the index i obtains a new value, available as a context for the interpretation of subsequent modalities. This is the formal counterpart of the informal explanation of modal interaction given above.
Now the second example reads as: $\Diamond_i^j p \wedge \Diamond_j^k q \wedge \Diamond_j^l r$, indicating that both (2b) and (2c) are to be interpreted as tests on situations where a lion has come in. This produces roughly the same truth conditions as the best approximation in ordinary modal logic, but *with* dynamic side effects and *without* the annoying incongruence between the surface forms in natural language and formal language that we saw above. (Consult (5) for a more detailed discussion of the update semantics.)

Monoidal interpretation

The second formalisation of modal interaction in discourse follows the monoidal approach of (8). The general format of the monoidal approach is that it uses a 'flat' representation language that consists of finite strings over an alphabet ALPH. Elements of the alphabet correspond to basic actions in (computer) memory: opening a new file, checking *one* value, etc. These basic actions are represented formally in an algebra with an associative operation, i.e., a *monoid*. We will call this monoid: m-STATES , and its operation: the *merger*.
The m-STATES play two roles. First, they serve as meaning objects, i.e., they are the things that expressions denote. Secondly, they stand for cognitive states: the state of mind of the hearer who is interpreting the text. m-STATES can be combined using the merger, which we will write as $\bullet$. The merger can be used to compute complex meanings by the recipe: $[\![\phi \cdot \psi]\!] = [\![\phi]\!] \bullet [\![\psi]\!]$. But the merger also serves to compute the update behaviour of a string on a cognitive state. The relation of this style of dynamics with other approaches in dynamic semantics is as follows: the common goal of *all* approaches to dynamic semantics is to make explicit some of the procedural details relevant to natural language interpretation. In (8) this is taken to the limit: procedural details have to be spelled out until we reach the stage where no complex operators are left. All that remains is a string language interpreted in a suitable monoid of m-STATES . This would become a tiresome exercise if we had to do it over and over again, each time we want to add some new phenomenon to our fragment. But fortunately (8) provides a systematic method for combining partial results, thus ensuring a sufficient degree of modularity. This means that, once the basics of the interpretation of several distinct phenomena has been implemented in the monoidal set up, a systematic way of combining the distinct accounts is automatically available. (Consult (8) for more details.)

In the monoidal account of modal interaction the alphabet will be:

$$\text{ALPH} = \{\bot, \lhd_\neg, \rhd_\neg\} \cup \{\lhd_j^i : i, j \in \text{IND}\} \cup \{\rhd_j^i : i, j \in \text{IND}\} \cup \{\oplus_i, \ominus_i : i \in \text{IND}\} \cup \{p : p \in \text{PROP}\}.$$

As before $\bot$ and the $p \in$ PROP are the basic formulas, expressing truth conditional information. The elements $\lhd_\neg$ and $\rhd_\neg$ demark the scope of a negation and $\lhd_j^i$ and $\rhd_j^i$ do the same for modalities. So, we use, for example, the string $\lhd_\neg \cdot p \cdot \rhd_\neg$ to express the negation of p. $\oplus_i$ and $\ominus_i$ are auxiliary characters and will be explained later on.
The string language is interpreted in a universe of m-STATES . For the interpretation of modal interaction we use m-STATES of the form: $\langle X, F\rangle$. X is a set of *finite stacking cells*, as introduced by Visser and re-explained in (6). We have one finite stacking cell for each variable name in $\text{VAR} = \text{IND} \cup \{val\} \cup \{l, n_1, n_2, m\}$. Here IND is as above, *val* stands for the current information state and the other identifiers are auxiliary. ¿From X we obtain a set R_X^+ that contains for each $x \in$ VAR the set of the memory locations that are relevant for the variable name x. One location will contain the current value of x, but there may be more locations around, for previous values of x, for example. F is a set of mappings from R_X^+ to sets of possible worlds: F represents the truth conditional information that we have.
There is special notation for some basic m-STATES that are used for elementary actions on the memory locations connected with the identifier x. We give some informal explanation.

id_x^+:	its R^+-set contains only one location, for the current value of x: $R^+ = \{x_{st1}\}$. There are no value-restrictions, so F consists of all mappings from R^+ to $\text{POW}(W)$.
push_x^+:	very much like id_x^+, but now $R^+ = \{x_{pu1}\}$, a new location for a fresh value of x. No value restrictions.
pop_x^+:	very much like id_x^+, but now $R^+ = \{x_{po1}\}$, a location for the previous value of x. Again no value restrictions.
$\mathsf{new}_x = \mathsf{pop}_x^+ \bullet \mathsf{push}_x^+$:	used when an old way of using x is exchanged for a new use of x. Hence two locations for x are involved: $R^+ = \{x_{po1}, x_{pu1}\}$. No value restrictions.

The notation convention for the referents in R^+ is such that the name indicates the identifier the location is associated with, as well as the status of the information in the memory location. For example, j_{st1} reads as: the current value of j; i_{pu1} as: the new value of i. By merging with these m-STATES we obtain the effect indicated by the informal explanation. For example, merging with push_x^+ will introduce a new memory location for a fresh value of x. And a merger with new_x has the combined effect of getting rid of, x_{po1}, an old location for x and reserving a new one, x_{pu1}.
There are also basic m-STATES that just introduce value restrictions on the current value of variables. For these we have notation $x = \mathtt{t}$, the m-state that restricts the value of x to $\mathtt{t}$. For example: $x = y$ has R^+-set $\{x_{st1}, y_{st1}\}$ and its F-set consists of those mappings $f : R^+ \to \text{POW}(W)$ such that $f(x) = f(y)$. Merging with the m-state $x = \mathtt{t}$ has the effect of restricting the current value of x as indicated by $\mathtt{t}$.
Combining such basic m-STATES we obtain all the required effects. For example, merging with $\mathsf{push}_x^+ \bullet x = y$, has the result of introducing a new memory location for x and setting its value equal to the current value of y. The full details of the proper definition of the m-STATES and their merger are in (6).
Each of the symbols in the alphabet ALPH gets an m-state as its interpretation. The interpretation of longer strings is then obtained using the (associative!) merger of m-STATES . The basic interpretations are:

$$
\begin{array}{lll}
[\![p]\!] & := & \mathsf{push}_l^+ \bullet (l{=}(V(p) \cap val)) \bullet \mathsf{new}_{val} \bullet (val{=}l) \bullet \mathsf{pop}_l \\
[\![\bot]\!] & := & \mathsf{new}_{val} \bullet (val{=}\emptyset) \\
[\![\triangleleft_\neg]\!] & := & \mathsf{push}_{n_1}^+ \bullet (n_1{=}val) \\
[\![\triangleright_\neg]\!] & := & \mathsf{push}_{n_2}^+ \bullet (n_2{=}val) \bullet \mathsf{new}_{val} \bullet (val{=}(n_1 \backslash n_2)) \bullet \mathsf{pop}_{n_2} \bullet \mathsf{pop}_{n_1} \\
[\![\oplus_i]\!] & := & \mathsf{push}_l^+ \bullet (l{=}i) \bullet \mathsf{push}_i^+ \bullet (i{=}l) \bullet \mathsf{pop}_l \\
[\![\ominus_i]\!] & := & \mathsf{pop}_i \\
[\![\triangleleft_j^i]\!] & := & \mathsf{push}_m^+ \bullet (m{=}val) \bullet \mathsf{new}_{val} \bullet (val{=}j) \\
[\![\triangleright_j^i]\!] & := & \mathsf{new}_i \bullet (i{=}val) \bullet \mathsf{new}_{val} \bullet (val{=}\left\{ \begin{array}{l} \emptyset \Leftarrow (i{=}\emptyset) \\ m \Leftarrow (i{\neq}\emptyset) \end{array} \right.) \bullet \mathsf{pop}_m
\end{array}
$$

A typical representation of a natural language modality in the string language looks like: $\triangleleft_j^i \cdot \phi \cdot \triangleright_j^i$, where $\triangleleft_j^i$ and $\triangleright_j^i$ indicate the the scope of the modality. The use of indices in the subscript and superscript is as before. Now example (2) above can be represented as: $\triangleleft_j^i \cdot p \cdot \triangleright_j^i \cdot \triangleleft_i^k \cdot q \cdot \triangleright_i^k \cdot \triangleleft_i^l \cdot r \cdot \triangleright_i^l$ This formula is interpreted as an m-state , $\langle X, F\rangle$, that has $R_X^+ = \{val_{pu1}, j_{st1}, i_{pu1}, k_{pu1}, l_{pu1}\}$. Each element in R_X^+ is a location in memory. F consists of exactly those mappings f that assign: to i_{pu1} the p worlds in $f(j_{st1})$; to k_{pu1} the q worlds in $f(i_{pu1})$; to l_{pu1} the r worlds in $f(i_{pu1})$; to val_{pu1} either $\emptyset$ or W, depending on whether one of $f(i_{pu1}), f(k_{pu1}), f(l_{pu1})$ is empty.
This is just the sort of information state suggested by the informal explanation in the introduction. Hence we now have two ways of formalising the interaction of modalities in discourse in such a way that the outcomes they produce for example (2) follow the informal explanation we started from. In the next section we provide a general comparison of the approaches, supported by a formal result.

From updates to monoids

In this section we want to compare the two approaches formally. We give a way of mapping each information state $\langle I, V\rangle$ from the update semantics into a corresponding m-state $(\langle I, V\rangle)^a$ in the algebra of m-STATES . Then we can use a mapping $(-)^a$ for translating formulas from the update language into the string language. For example: $(\Diamond_j^i p)^a = \triangleleft_j^i \cdot p \cdot \triangleright_j^i$. Once we will have these two mappings, we can check formally that updating and merging always amount to the same thing, modulo the translation and the embedding. Regrettably there is no room to provide all the details of the mappings involved. (More can be found in (6).) But perhaps the following selection of details suffices to get across the general ideas and some complications we meet. So let's look at some details.
First we consider the translation of the update language, $\mathcal{L}_m$ say, to the string language, $\mathcal{L}_a$. Here the basic idea is to map $\Diamond_j^i \phi$ to $\triangleleft_j^i \cdot \phi \cdot \triangleright_j^i$ and $\neg\phi$ to $\triangleleft_\neg \cdot \phi \cdot \triangleright_\neg$. There is a complication, however, caused by the limits on the external dynamics in the semantics of $\mathcal{L}_m$: $\Diamond_j^i \phi$ introduces a new value for i, but in nested occurrences, as in $\neg\Diamond_j^i \phi$ and $\Diamond_k^l \Diamond_j^i \phi$ this dynamic effect is overruled. Only outermost occurrences of $\Diamond$s introduce new values for indices. But *internally* there is no limit on the dynamic interaction: inside $\Diamond_k^l(\Diamond_j^i p \wedge \Diamond_i^m q)$ a new value for i has to be passed on for the evaluation of q. In the translation we overcome this complication in two steps: (i) normal forms for the formulas of $\mathcal{L}_m$ are introduced, systematically re-bracketing formulas of the form $\phi \wedge (\psi \wedge \chi)$ to $(\phi \wedge \psi) \wedge \chi$; (ii) an auxiliary translation $(-)^b$ is used, that blocks dynamic effects. This is where $\oplus_i$ and $\ominus_i$ come into play: they help to regulate the blocking and de-blocking of dynamic side effects. In the end we will get translations:

$$
\begin{array}{lll}
(\Diamond_j^i \phi)^a & = & \triangleleft_j^i \cdot \phi \cdot \triangleright_j^i \\
(\Diamond_k^l \Diamond_j^i p)^a & = & \triangleleft_k^l \cdot \oplus_i \cdot \triangleleft_j^i \cdot p \cdot \triangleright_j^i \cdot \ominus_i \cdot \triangleright_k^l \\
(\Diamond_k^l(\Diamond_j^i p \wedge \Diamond_i^m q))^a & = & \triangleleft_k^l \cdot \oplus_i \cdot \triangleleft_j^i \cdot p \cdot \triangleright_j^i \cdot \oplus_m \cdot \triangleleft_i^m \cdot q \cdot \triangleright_i^m \ominus_m \cdot \ominus_i \cdot \triangleright_k^l
\end{array}
$$

whereby we make sure that there are no lasting dynamic effects on i and m. Full details are in (6).
We complement the translation $(-)^a$ by a natural embedding $(-)^a$ that sends the information states from the update setting to the m-STATES of the monoidal set up: $\langle I, V\rangle^a = \langle X, F\rangle$ is such that the R_X^+-set has one memory location for each index in IND and one for val. F restricts the values of these locations as indicated by $\langle I, V\rangle$: the value of val will be restricted to I, the value of $i \in$ IND to $V(i)$. Here we see the double role of the m-STATES : they correspond to cognitive states, which is why we can embed the information states of the update setting in m-STATES . But they also serve as denotations of formulas, which is why it makes sense to translate the formulas with update modalities to formulas of the string language. The combined claim about the translation and embedding is that:

$$\langle I, V\rangle^a \bullet [\![\phi^a]\!] \equiv (\langle I, V\rangle [\![\phi]\!])^a$$

for each $\phi \in \mathcal{L}_m$. This means that the effect of the translation ϕ^a in the algebraic setting, is the same as an update with ϕ in the update semantics. This general result implies that the flat representation language matches the modal language *qua* 'empirical coverage': $(-)^a$ turns any suitable representation in the language with indexed modalities into a suitable representation in the string language. However, the algebraic approach has some additional advantages: it gives an explicit and precise account of the underlying dynamics. This is both heuristically and computationally attractive: it forces us to avoid updates by magic and hence ensures a level of computational realism that update semantics *per se* does not offer.

Conclusion

We have discussed examples of the interaction of modal expressions in discourse. The intuitive explanation of this interaction is that a modal depends on a contextually given set of possibilities *and* adds a new set of possibilities to the context, that can be used by subsequent modalities.
Two styles of formalisation of this explanation were considered, both in dynamic semantics. One uses a representation language with indexed modalities and gives an update semantics for this language. The other, 'monoidal' approach uses a string language with an interpretation in an algebra of m-STATES . Both styles allow us to represent the crucial example. For a more general comparison we have a systematic translation between the formalisms that preserves meaning. We conclude that the monoidal approach is at least as well suited for the representation of modal interaction in discourse. In addition the monoidal approach forces us to avoid magical updates and thus ensures a level of computational realism that update semantics *per se* does not offer.
Another advantage of the monoidal setting of (8) is that it is designed to facilitate the combination of accounts of different phenomena. This will prove useful, as there are several discourse phenomena in which a similar dynamics of information seems to be involved. For example, quantificational subordination, E-type anaphora and temporal anaphora all provide cases of flow of information strikingly similar to the ones we discussed for modalities. Consider as an example a case of quantificational subordination:

> Most lions will come in. Some will see you first. Some will see me instead.

In this example *Some* picks up the set of (all) lions that come in, a set which is introduced by the quantifier *Most* in the first sentence. The information flow is just as in the examples of modal subordination above. Hence we predict that an

account of the basic dynamics involved in these phenomena can also be given in a similar way. In particular, a formalisation in the monoidal setting can be obtained. Then the modularity that has been built in in (8) ensures that an account of the interaction between modalities and quantifiers, as in:

Most lions will come in. They might eat you first.

is relatively easily available. Of course some dirty work in the (near) future is required to substantiate this prediction.
Other work in the near future concerns the investigation of more involved patterns of interaction. So far we have been concerned with examples of modal subordination. But more involved modes of interaction are also available. Consider, as an example, the following discourse fragment:[2]

(3) Morgen kan ze zwanger (blijken te) zijn. Het kan ook nog vandaag. Het kan van de behanger zijn, Of van een Franse zanger zijn, Of iemand uit Den Haag.	(3') Tomorrow we might find out she is pregnant. Or we might find out already today. It could be from the upholsterer, Or from a French chansonier, Or someone from The Hague.

Here the meaning of the discourse can be approximated by: ($\Diamond$tomorrow $\wedge$ $\Diamond$today) $\wedge$ (tomorrow $\vee$ today $\rightarrow$ $\Diamond$ upholsterer) $\wedge$ (tomorrow $\vee$ today $\rightarrow$ $\Diamond$ chansonnier) $\wedge$ (tomorrow $\vee$ today $\rightarrow$ $\Diamond$ the-hague). Hence some form of *introduction* and *summation* of alternative contexts is involved: two alternatives, tomorrow and today, *jointly* provide the context for the interpretation of the three subsequent modalities. In order to cover such examples an extension of the logic is required. In (7) we have started taking stock of complex modes of interaction: we have collected over one hundred examples of modal discourses from a corpus of texts to see which types of interaction actually occur. Once this fase of stock taking is more or less completed, we intend to proceed by developing an extension of the logic to cover the complex patterns of modal interaction we find in the corpus.

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[2]The Dutch text is from the famous Dutch song *Op een mooie Pinksterdag*, lyrics: A. Schmidt, music: H. Bannink.

Focus and Topic Sensitive Operators

Maria Aloni — University of Amsterdam
David Beaver — Stanford University
Brady Clark — Stanford University

Background

Sentences like "Anna only gave BILL chocolate" are commonly analyzed as involving a dependency between the placement of intonational focus[1] and the division of material between the restriction and scope of *focus sensitive particles* (FSP) like *only*. A word is *focus sensitive* if its semantics involves essential reference to the information structure of the sentence containing it.

A number of lexical items and constructions have been identified as *focus sensitive* in English, notably *only*, *even*, *too*, *also*, *always*, *usually*, *never*, *because*, generics, negations, questions and counterfactual conditionals. It is standardly assumed by most theories of focus that the class of FSPs is homogeneous; i.e. that there is a single mechanism responsible for focus sensitivity, and that all FSPs are sensitive to the same things, e.g. intonational focus in English.

In this paper, we present data that shows that the standard account of FSPs is seriously flawed. We argue that a dynamic model of accommodation along the lines of that developed in Beaver (1994), combined with the proposal for modeling the dynamics of domain restriction in Gawron (1996), can account for the data concerning FSPs in a non-stipulative way. In particular, we argue (1) that whereas some FSPs are directly sensitive to focus, others are in fact sensitive not to sentence focus but to discourse topic, and (2) that the same formal mechanism can be used for representing information associated with both topics and foci.

Theories of Focus Sensitive Particles

Following Rooth (1992), theories of FSPs can be divided into three groups which can be characterized as **semantic**, **hybrid** and **pragmatic**[2]. In semantic accounts, the interpretation of FSPs is structurally linked to intonationally marked focus. In pragmatic accounts, pragmatic factors alone link FSP interpretation to focus. In hybrid accounts of FSPs like Rooth (1992), structural and pragmatic constraints explain FSP interpretation.

(1) **Theories of Focus Sensitive Particles**

Semantic	Hybrid	Pragmatic
Chomsky (1972) Rooth (1985) von Stechow (1985/1989) Krifka (1992), Krifka (1993) Rooth (1996)	Rooth (1992) Rooth (1995)	Jackendoff (1972) von Fintel (1994) Roberts (1995), Roberts (1996) Schwarzschild (1997) Geurts and van der Sandt (1997)

Let us make a division between Class A FSPs, including adverbs of quantification (e.g. *always*, *usually*), and some additive particles like *also*, and Class B FSPs, including *only* and *even*. It is rare for one theory of focus sensitive particles to cover both classes in detail, although many authors examining members of one class suggest at least implicitly that their theory will cover both[3]. Thus von Fintel

[1]Capitals denote focal stress, which in most cases discussed would be transcribed as an H* L-L% in the ToBi system.

[2]In fact Rooth uses the terminology *weak/intermediate/strong*. See (1) for discussion.

[3]In Rooth (1985) and subsequent work, Rooth utilizes two architectures for the range of FSPs: a Discourse Representation Theory semantics for adverbs of quantification and a Montague grammar semantics for *only/even*. However, he does not motivate this division of labour in terms of different focus-sensitivity, but in terms of quite separate difficulties with binding and anaphora.

(1994), Rooth (1995) and Gawron (1996) are all accounts of Class A but not Class B, while Rooth (1992), Krifka (1993) and Roberts (1996) are accounts of Class B but not Class A. In the next section, we claim that **no** current theory accounts adequately for both classes.

Data

In this section, we discuss original data which shows that a theory which treats FSPs as a homogeneous class is hopelessly flawed. We take *always* as representative of Class A and *only* as functioning parallel to *even*.

Extraction

Consider the following scenario: I have two roommates, Kim and Sandy. I always stock my roommates' fishtanks. I stock Sandy's fishtank with goldfish and nothing else. I stock Kim's fishtank with goldfish and clownfish.

Sandy's fishtank	Kim's fishtank
goldfish	goldfish and clownfish

(2) KIM's is the tank I said I always stock with clownfish.

(a) "I said I always stock KIM's tank with clownfish."

(b) "I said I always stock Kim's tank with CLOWNFISH."

(3) # KIM's is the tank I said I only stock with clownfish.

(a) "I said I only stock KIM's tank with clownfish."

(b) "I said I only stock Kim's tank with CLOWNFISH."

In (3) the focus of *only* is extracted. Surprisingly, (3) lacks the reading given in (3a). (2) has the readings in both (2a) and (2b). This data suggests that the extraction of the focus of *only* is impossible, but the extraction of the focus of *always* is possible.

Italian behaves similarly to English as far as extraction is concerned. (4) and (5) are illustrative of the interaction between *solo* ('only') and *sempre* ('always') and extraction. (5) cannot mean 'Giulia knows which boy Mary has only brought HIM to the cinema (and nobody else)".

(4) Giulia sa quale ragazzo Maria ha sempre portato al cinema.
"Giulia knows which boy Maria has always brought to the cinema."

(5) Giulia sa quale ragazzo Maria ha solo portato al cinema.
"Giulia knows which boy Maria has only brought to the cinema."

Dutch, German and Swedish show a similar pattern.

Presupposition

In some cases the domain of *always* can apparently be restricted by presupposition, although *only* remains tied to intonational focus (c.f. Cohen (1999)). Consider examples (6) and (7):

(6) Mary always remembers to go to CHURCH.

(a) ? "Whenever Mary remembers to do something, it's always to go to church."

(b) "Whenever it's time for church, Mary remembers to go."

(7) Mary only remembers to go to CHURCH.

(a) "The only place Mary remembers to go is to church."

(b) # "The only thing Mary does when it's time for church, is remember to go."

Discussion

The extraction and presupposition data show that there are distributional differences between Class A and Class B FSPs. A formal framework which treated FSPs as a homogeneous class would fail to capture these differences.

Regarding the extraction data, consider semantic accounts. These must insist on the focus of a FSP being in the scope of the FSP at some level of representation. There are two options. Either (i) traces (gaps) can carry focus at this level, or (ii) they cannot. If (i), then such accounts incorrectly predict that (3a) is a possible reading. If (ii) they incorrectly predict the absence of reading (2a)[4].

Consider now pragmatic accounts. Here the absence of reading (3a) is a counterexample. For such approaches the syntactic form of the sentence plays no role in determining the alternative set. So these theories can not distinguish between a variant of (3) with focus on *Kim's* and sentence (3a) itself, in which the focus is not extracted from the syntactic scope of *only*.

Formal Framework

In this section, we will briefly describe the essential features of the adopted formalism.[5] The main idea consists in interpreting intonation in terms of presupposition of topics under discussion. Topics under discussions are formalized as domain restrictions in the sense of Gawron (1996). Presupposition and accommodation are analyzed as in Beaver (1995). The quantificational domain of adverbial quantification (Class A FSPs) is crucially restricted by the topics under discussion. The domain of quantification of *only* (a Class B FSP) is restricted to some subset of the domain of objects of the same semantic sort as the focused material in their scope.

Sentences are interpreted as context change potentials, where a context is a pair consisting of an environment e and an information state s. Information *states* are defined as in Heim (1983) as sets of world-assignment pairs, and an *environment* is defined, as in Gawron (1996), as a partial function from variables to states in which the variable is defined. States encode what is known and what discourse markers are available for future anaphora; environments encode information about what is under discussion. It is crucial that the two kinds of information are stored separately.

Topics under Discussion The topics under discussion are the things the discourse is about. They are formalized as in Gawron (1996) in terms of domain restrictions. Questions are typical examples of expressions introducing topics, this

[4] It is crucial to this argument that in (2), *always* takes scope under *said*. Since the *saying* event is not bound by *always*, it cannot be claimed that *always* takes wide scope at LF. This provides our justification for maintaining that the subject of the main clause, which is the semantic focus of *always*, is neither within the syntactic scope nor the binding domain of *always*.

[5] This framework is further developed in Aloni, Beaver and Clark (in preparation). Please contact the authors for further details.

justifies our choice of denoting by $?x\phi$ the operation of introduction or further specification of the topic 'what about ϕ'.[6] Following Gawron (1996), although adapting notation somewhat, we assume that the update of a context s_e with $?x\phi$ yields a context $s_{e'}$ such that $e'(x)$ is defined and is a state which supports at least the information that x is ϕ. The update of s_e with a quantified sentence $Qx\psi$ will crucially depend on $e(x)$ which encodes all of the restrictions that has been placed on x along the preceding discourse.

Accent The general picture is that intonation signals two features F(ocus) and N(on-)N(ovel). F and NN are represented as presupposed topics under discussion which can be accommodated. Following Krifka (1999), we assume that we have (at least) the two features F and NN realizable in the sentence.[7] The first role of the Focus feature F is to trigger the presupposition that the background is among the topics under discussion. The sentence in (8) is represented as in (9):

(8) John loves $[\text{Mary}]_{\text{F}}$.

(9) $\partial[?xL(j,x)] \wedge \exists x(x = m)$

The sentence presupposes the previous introduction, as topic, of a set of individuals (those loved by John) and asserts that the item in focus (Mary) belongs to that set. A typical example of a sentence introducing such a topic would be the question: 'Who does John love?' The Non-Novel feature NN is interpreted as presupposing an identical antecedent. The sentence in (10) receives the representation in (11):

(10) $[\text{A dog}]_{\text{NN}}$ is INTELLIGENT.

(11) $\partial[?xD(x)] \wedge \exists xD(x) \wedge I(x)$

Intuitively the sentence presupposes that dogs are among the topics under discussion at the moment of utterance.

Focus and Topic sensitive operators [8] *Adverbs of quantification* are analyzed as in the Lewis-Heim-Kamp tradition. They form tripartite structures where if/when clauses, if present, provide the restriction. The topics under discussion which are relevant for the interpretation of the sentence crucially determine what is actually quantified over by the adverb.

(12) $\text{Quantifier}_{(Topics)}$(Restriction)(Nuclear Scope)

The sentence in (13) is represented as in (14).

(13) $[\text{A dog}]_{\text{NN}}$ is always INTELLIGENT.

(14) always $(\emptyset)$ $(\partial[?xD(x)] \wedge \exists xD(x) \wedge I(x))$

[6] An analysis of questions in terms of domain restrictions is a promising one. From domain restrictions we can define partitions and all of the relevant notions for a theory of questions and answers (cf. Groenendijk and Stokhof (1984)). Furthermore, we would have a natural characterization of the notion of a congruent answer (cf. von Stechow (1991)).

[7] The prosodic effect of the F feature is that the item receives a H* L-L% in the ToBi labeling system. The prosodic effect of NN is that it prevents the item from receive a pitch accent and this means that the accent has to be realized elsewhere. According to Krifka, the NN item is deaccented or it has a secondary accent realized as low-rise. In our analysis, it is not essential that the NN feature be identifiable, except in cases where a topic must be accommodated. If a topic is already present in the discourse context, then domain restriction effects for class A FSPs can be achieved simply by co-indexation.

[8] Aloni, Beaver and Clark (in preparation) will provide a fully detailed analysis of *only* and adverbial quantification in this framework.

The adverb is analyzed in such a way that it actually quantifies over all the variables introduced in its scope which are defined in the environment at the moment of interpretation. In this case, since the sentence is defined only in contexts in which the topic $?xD(x)$ has already been introduced, the variable quantified over is x and the domain of quantification of the adverb is automatically restricted to dogs. The sentence means: "All dogs are intelligent."

A first role of the focus feature was mentioned above, that of introducing a certain presupposition. The second function of the focus feature is to identify the focussed variable to class B FSPs such as *only*. The interpretation of *only* involves a universal quantification automatically restricted by the presupposition expressed by the F feature. The sentence in (15) receives the representation in (16). Note that although an existential binds x, the FSP *only* has the effect of changing the quantificational force, in much the same way as in the standard dynamic analysis of unselective binding.

(15) John only loves $[\text{MARY}]_{\text{F}}$.

(16) $\text{only}_x(\partial[?xL(j,x)] \wedge \exists x(x = m))$

(16) is interpreted as asserting that all x are equal to Mary. Since the sentence is defined only in contexts in which the topic $?xL(j,x)$ has already been introduced, the domain of quantification will contain only individuals who John loves. The sentence means "John loves nobody but Mary."

Results The formal system has enough structure to capture the difference between the (a)-(b) cases in the following two examples:

(17) a. A DRUMMER always lives in [a half empty building]$_{\text{NN}}$.

b. [A drummer]$_{\text{NN}}$ always lives in a HALF EMPTY BUILDING.

(18) a. Mary only$_i$ introduced $[\text{JOHN}]_{F_i}$ to Bill.

b. Mary only$_i$ introduced John to $[\text{BILL}]_{F_i}$.

By incorporating accommodation in the notion of entailment (cf. Beaver (1995)), we can prove the following facts:

(19) (a) always $(\emptyset)$ $(\partial[?xB(x)] \wedge \exists yD(y) \wedge \exists xB(x) \wedge L(x,y)) \models \forall x(B(x) \rightarrow \exists yD(y) \wedge L(x,y))$

(b) always $(\emptyset)$ $(\partial[?yD(y)] \wedge \exists yD(y) \wedge \exists xB(x) \wedge L(x,y)) \models \forall y(D(y) \rightarrow \exists xB(x) \wedge L(x,y))$

Thus (17a) means "All half empty buildings house drummers." and (17b) means "All drummers live in half empty buildings."[9]

(20) (a) $\text{only}_x(\partial[?xI(m,x,b)] \wedge \exists x(x = j)) \models \forall x(I(m,x,b) \rightarrow x = j)$

(b) $\text{only}_x(\partial[?xI(m,j,x)] \wedge \exists x(x = b)) \models \forall x(I(m,j,x) \rightarrow x = b)$

[9] The accents in these sentences could also be analyzed as marking focus rather than non-novelty. In this case the first sentence would mean: "All half empty buildings which house somebody, house drummers." and the second sentence would mean "All drummers who live somewhere, live in an half empty building."

(18a) means "Mary did not introduce anybody but John to Bill." and (18b) means "Mary did not introduce John to anybody but Bill."

Among the advantages of representing intonation as presupposed domain restrictions is that the so called requantification problem[10] is avoided. A further advantage is that we have a straightforward account of the fact that the quantificational domains of *only* or *always* can be further restricted by the context. Domains of quantification are constructed by combining constraints that arise from different sources and given the dynamics of the system, we can account for the anaphoric nature of these restrictions (cf. Jäger (1995)).

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[10] First observed Rooth (1995), the requantification problem is discussed by von Fintel (1994) who invented the name and more recently by Krifka (1999).

The Logic of Anaphora Resolution[1]

David Beaver
Stanford University

Abstract

This paper concerns the semantics/pragmatics interface for natural language, and in particular the question of how anaphora resolution should be orchestrated in a dynamic semantics. Previous dynamic systems such as DPL have relied on preindexation of anaphors and antecedents. It is argued that this represents a serious inadequacy. A dynamic semantic system, RPL, is proposed which eliminates the need for preindexation, by combining an "Amsterdam-style" dynamic semantics with a pragmatic module. The semantics uses a novel extension of DMPL information states, in which ambiguity of anaphors is represented using multiple referent systems. It is argued that the resulting system not only provides a marked empirical improvement over dynamic predecessors, but also provides a quite general approach to the semantics/pragmatics interface.

1 Introduction

There is a bizarre assumption made in Groenendijk and Stokhof's Dynamic Predicate Logic [GS91a] and Dynamic Montague Grammar [GS91b], and Heim's File Change Semantics [He82], an assumption that is not made in Kamp's Discourse Representation Theory [KR93]. This is the assumption that anaphor-antecedent relationships are presented 'gift-wrapped' to the semantics in the form of pre-indexed NPs.[2] Who or what is supposed to do the wrapping is unclear.

Perhaps syntax does the job of pre-indexation? Yet syntax seems unlikely to do more than provide a few extra local constraints on resolution via C-command conditions etc. If not syntax, then presumably pragmatics must do the job. But this would not sit well with what appears to be the architecture of DPL, DMG and FCS. For it seems that pragmatics should either operate after semantic interpretation, as is assumed e.g. in classic work on pragmatics by Grice, Austin and Searle, or at least should operate in tandem with semantics.

In [Be99], a general approach to ambiguity resolution in Dynamic Semantics is proposed. Here I exemplify this approach in the domain of anaphora resolution, by showing how a dynamic semantics can be formally combined with a pragmatic resolution module. For the purposes of this extended abstract, I use a naive form of parallelism for resolution.[3] The result dispenses with the indexing assumption, so that indexation can no longer be seen as a point dividing DRT

[1] This extended abstract draws on material in [Be99], but extends that work formally. Thanks in particular to Maria Aloni and Paul Dekker.

[2] In this respect Musken's "Compositional DRT" [Mu96] is not like DRT but like DPL/DMG/FCS, since it does assume pre-indexation.

[3] In a longer version of the paper, available on request, I show how the Centering model [GJW95] can be substituted.

from other dynamic systems. In fact RPL provides a model of resolution empirically superior to standard DRT, since RPL incorporates pragmatic constraints on resolution which are not found in standard DRT[4].

The system developed is predicate logical, but involves non-standard operators and conventions. The semantics uses a notion of information state from DMPL [GSV95], but adapts the *referent systems* used there to entirely new purposes. Referent systems mediate between syntactic variables (henceforth *referents*) and discourse entities (for Groenendijk et al, *pegs*). In DMPL, as in the earlier [Ve94], a referent system is used to prevent requantification over a variable from destroying information about the discourse entity that the variable picks out. In RPL, while this role remains, referent systems have two additional functions. First, they represent uncertainty about which discourse entity a given syntactic variable refers to, and, second, they perform a bookkeeping role, maintaining information about the grammatical role (e.g. subject) of the last NP to refer to each discourse entity. To represent uncertainty, multiple referent systems are allowed in a single information state, a possibility not found in [GSV95], and which necessitates a modified notion of entailment.

2 Semantics

The semantics for RPL is similar to that for DMPL. There are two new operators: ρx introduces the referent x as a pronoun, which must be interpreted as picking out the same discourse entity as some previous referent, and $[\phi]$ is the resolution of ϕ.

Definition D1 **(Models, Information States)** *(i)* Models *are pairs* $\langle W, D\rangle$ *of a non-empty set of worlds and a non-empty domain of individuals. (ii) A* world *is a function from individual constants to members of* D*, and from n-ary predicate constants to sets of n-tuples of elements of* D*. (iii) An* assignment function g *is a finite sequence of members of* D*. For an n-member sequence,* n *is the* domain *of the function. For a positive integer* $r \leq n$*,* $g(r)$ *is the* r*-th member of the sequence. (iv) A* referent system r *is a function from referents to integers (these integers being understood as members of an associated assignment function.). (v) An* information state s *is a set of* possibilities *defined relative to some model,* $\langle W, D\rangle$*. A possibility* i *is a triple* $i = \langle r, g, w\rangle$ *of a referent system, an assignment function and a world, such that the range of* r *is within the domain of* g*, the range of* g *is within the domain of the model,* D*, and* $w \in W$*. The minimal information state* $\odot$ *is* $\emptyset \times \emptyset \times W$*, where* $\emptyset$ *is a function with zero domain.*

[4]Similar in spirit to the present enterprise is Roberts' proposal in [Ro98], which discusses how a sophisticated pragmatic theory might be combined with DRT. The strength of her theory, its sophistication, is also a weakness, in the sense that Roberts relies upon an incompletely specified theory of text structure and communicative intention. In that sense, the proposal in the current paper is less ambitious, but more strongly predictive.

Definition D2 **(Semantics: basic clauses)**

$$
\begin{aligned}
s[\![Rt_1 \ldots t_n]\!] &= \{i \in s \mid \langle i(t_1), \ldots i(t_n)\rangle \in i(R)\} \\
&\quad \textit{and is undefined if any component } i(\alpha \textit{ is undefined.} \\
\langle r, g, w\rangle(\alpha) &= w(\alpha) \textit{ for } \alpha \textit{ an individual or predicate constant} \\
&\quad g(r(\alpha)) \textit{ for } \alpha \textit{ a referent in the domain of } r \\
&\quad \textit{and otherwise is undefined.} \\
s[\![t_1 = t_2]\!] &= \{i \in s \mid i(t_1 = i(t_2)\} \\
s[\![\neg\phi]\!] &= \{i \in s \mid i \textit{ does not subsist in } s[\![\phi]\!]\} \\
s[\![\phi \wedge \psi]\!] &= s[\![\phi]\!][\![\psi]\!] \\
s[\![\exists x\phi]\!] &= \bigcup_{d \in D}(s[x/d])[\![\phi]\!]
\end{aligned}
$$

Two ways of adding referents are now defined. The notation $s[x/d]$ is familiar from DMPL, with one slight modification. $s[x/d]$ means the variant of s in which the referent x is mapped to a new discourse entity, which in turn all assignment functions map to d. Whereas in DMPL the discourse entity that x is mapped to is determined in terms of the range of the referent systems in s, below I use instead the domain of the assignment functions in s.[5] The notation $s[x \downarrow n]$ is used to denote the variant of s in which all referent systems have been modified so that the referent x is mapped to the discourse entity n, which should be in the domain of assignment functions in s.

Definition D3 **(Referent setting, extension)**
Let $i = \langle r, g, w\rangle \in I$*;* $i' = \langle r', g', w'\rangle \in I$*;* n *is the largest integer in the domain of* g*;* $d \in D, s \in S$*.*

$$
\begin{aligned}
s[x/d] &= \{i[x/d] \mid i \in s\} \\
i[x/d] &= \langle r[x/(n+1)], g[(n+1)/d], w\rangle \\
i \leq i' &\ \textit{iff}\ g \subseteq g',\ \&\ w = w' \\
i \textit{ subsists in } s &\ \textit{iff}\ \exists i' \in s\ i \leq i' \\
s[x \downarrow n] &= \{i[x \downarrow n] \mid i \in s\} \\
i[x \downarrow n] &= \langle r[x/n], g, w\rangle \\
\textit{d-entities}(s) &= \{n \mid \exists\langle r, g, w\rangle \in s\ \ n \in \textit{dom}(g)\}
\end{aligned}
$$

An operator is now defined which introduces a new referent, but leaves it indeterminate between all the discourse entities which have been introduced previously:

Definition D4 **(Anaphoric operator)**

$$s[\rho x]s' \quad \textit{iff} \quad s' = \bigcup_{n \in \textit{d-entities}(s)} s[x \downarrow n]$$

[5]The reason for this is that referent systems will occasionally be reset, losing information about which referents have been introduced.

Definition D5 **(Entailment, Possible Entailment)**

$$\begin{array}{rcl} \phi \models \psi & \textit{iff} & \odot[\![\phi]\!] \leq \odot[\![\phi]\!][\![\psi]\!] \\ \textit{resolutions}(s) & = & \{t \mid \exists r\ t = \{\langle r', g, w\rangle \in s \mid r = r'\} \neq \emptyset\} \\ \phi \rightsquigarrow \psi & \textit{iff} & \exists s \in \textit{resolutions}(\odot[\![\phi]\!]) \rightarrow \exists t \in \textit{resolutions}(s[\![\psi]\!])\ \ s \leq t \end{array}$$

In the above, $\rightsquigarrow$ should be read as "possibly entails", i.e. there is a way of resolving ρ-referents such that the the antecedent entails the consequent, although there may be other ways of resolving referents so that this is not the case.

Consider the argument: " Jane likes Mary. Therefore, she likes someone." We translate this as the following valid argument pattern: $\exists x\ x = j \wedge \exists y\ y = m \wedge \text{likes}(x, y) \rightsquigarrow \rho u \wedge \exists v\ \text{likes}(u, v)$

3 Ambiguity and Anaphoric Resolution

Transition Preference Pragmatics, introduced in [Be99] is a general approach to the semantic-pragmatics interface in a dynamic setting. The proposal is that compositional derivation fixes a set of possible state transitions, and that pragmatics ("to a first approximation") merely provides a preference ordering over the alternative transitions. This approach will now be exemplified with respect to RPL.

Let us require that referents be integers. We will then assume a convention whereby in the translation of sentences of English to RPL, the integers are chosen according to some algorithm based on grammatical obliqueness, so that e.g. the subject of a main clause is always translated using the referent *1*.

Formulae of RPL, if they involve ρ-formulae, can lead to unresolved states, in which it is uncertain which discourse object is referred to by a given referent. The output of such a formula can be split up into alternative *resolutions*, as we have seen. Suppose that for some input s, there is a set of alternative resolutions τ. How can we select the *best* member of τ? That is the job which a pragmatic theory must be able to answer. But here, rather than delving into the question of which is the right pragmatic theory, I propose a token theory to show how in principle the job can be done.

The token theory can be stated as follows: (1) transitions will be ranked according to the degree of parallelism between input and output; (2) parallelism will be measured by the number of referents in the output which are mapped onto the same discourse object as the corresponding referent in the input; (3) a preference will be assumed for parallelism of referents introduced by the syntactically least oblique NPs. Thus we will prefer transitions that maintain subject parallelism, but if that fails to decide, we will prefer transitions providing direct object parallelism, and so on. This is the basis of the *max* predicate, introduced below: $max_s(\tau)$ picks out the subset of resolutions in τ which are most strongly parallel with s.

Definition D6 **(Maximal Transitions)**

$$\begin{array}{rcl} \mathcal{R}(s) & = & r \textit{ iff } \forall\langle r', g, w\rangle \in s\ r = r' \\ max_s(\tau) & = & \{t \in \tau \mid \neg\exists u \in \tau\ \exists n\ \ \mathcal{R}(s)(n) = \mathcal{R}(u)(n) \neq \mathcal{R}(t)(n)\ \&\ \\ & & \forall n' < n\ \ (\mathcal{R}(s)(n') = \mathcal{R}(t)(n')\ \Leftrightarrow\ \mathcal{R}(s)(n') = \mathcal{R}(u)(n'))\} \end{array}$$

I now define a resolution operator [.] which utilizes the definition of maximal transitions. The input, s, of $[\phi]$ should be the output of a previous formula. A variant of s with all component referent systems emptied of information (the effect of "*clean*") is updated with ϕ to produce an intermediary state which may involve unresolvedness. The predicate *resolutions* breaks this state up into alternative fully resolved outputs, and the predicate *max* selects between these. To allow for the possibility of multiple maximal states, the union of maximal states is taken to produce the final output. In most cases this will be a fully resolved state, and will be the output which involves maximal parallelism with the input.

Definition D7 **(Resolution Operator)**

$$\begin{array}{rcl} \textit{clean}(s) & = & \{\langle\emptyset, g, w\rangle \mid \exists r\langle r, g, w\rangle \in s\} \\ s[\![[\phi]]\!] & = & \cup max_s(\textit{resolutions}(\textit{clean}(s)[\![\phi]]\!])) \end{array}$$

In the example below, the parallelism constraint favors outputs of the second sentence of (A) which map referent 1 onto the same discourse entity as in the outputs of the first sentence. It is thus an easily demonstrated formal property of the system defined that the translation of the discourse in (A) entails that of the sentence in (B).

(A) A soldier meets a sailor. She likes her.
$\exists 1\ \text{soldier}(1)\ \wedge\ \exists 2\ \text{sailor}(2)\ \wedge\ \text{meets}(1, 2)$
$\wedge\ [\rho 1 \wedge \rho 2 \wedge \text{likes}(1, 2)]$

(B) A soldier likes a sailor.
$\exists 1\ \text{soldier}(1)\ \wedge\ \exists 2\ \text{sailor}(2)\ \wedge\ \text{likes}(1, 2)$

4 Discussion

RPL is a methodological stepping stone on the way to a fragment of natural language. The latter could be achieved using an embedding into type theory, following the approach pioneered in [Mu96], although this goes beyond the scope of the current paper.

The RPL approach to dynamic ambiguity resolution is quite general. RPL itself will make correct predictions about anaphora only to the extent which the parallelism analysis itself makes correct predictions. But in principle, any theory of resolution which could be expressed as a preference ordering over alternative

transitions could be used instead of parallelism, including theories which defined only a partial ordering, and thus left pronoun reference underspecified.

Finally, anaphora resolution is only one aspect of the semantics/pragmatics interface. The current approach should generalize to other areas of ambiguity resolution and to presupposition accommodation. Indeed, the latter phenomenon has already been analyzed using orderings related to those used here in [Be95], and it remains for future work to combine these approaches.

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Plural Predication and Partitional Discourses

Sigrid Beck, University of Connecticut

Summary

This paper argues against Schwarzschild's (1996) proposal that the interpretation of relational plural sentences is constrained by a contextually determined relation. Instead, I suggest that the data that seem to indicate the use of such relations are to be reanalysed as hidden universal quantification. This captures the fact that the only relations that seem to be available are equivalence relations. We come back to Krifka's (1989) proposal of a polyadic plural operator to handle cumulative readings of relational plurals and extend it to affect the situation/event argument of the relation.

1. Relational Plural Sentences

Relational plurals are sentences in which two plural NPs are connected by a two-place relation. Relational plural sentences come in a puzzling variety of interpretations. (1) is most likely interpreted in terms of universal quantification over the members of the two groups denoted by the two NPs. This is indicated in (1').

(1) The judges can see the performers.

(1') $\forall x \in J$: $\forall y \in P$: x can see y

Such an interpretation is too strong for (2). (2a) is interpreted as in (3). This reading will be referred to as a cumulative reading; such an interpretation is much weaker in terms of quantification over group members.

(2) a. The lines of R1 are parallel to the lines of R2. [Scha (1984)]

b. Although the couples in our study were not married, the women showed aggressive behaviour towards the men. [following Schwarzschild (1996)]

(3) $\forall x \in LR1$: $\exists y \in LR2$: x parallel to y & $\forall y \in LR2$: $\exists x \in LR1$: x parallel to y

(2b) is similar to (2a) with respect to how many members of the two groups have to stand in the relation to each other. But we tend to interpret the sentence in a more specific way than (2a) in that it is not sufficient that a woman showed aggressive behaviour towards an arbitrary man - it has to be her partner. This paper is about contrasts like (2a) vs. (2b).

2. Cumulation and Salient Relations

Let's start with simple cumulative readings. The cumulative reading of (4) is described in (5). One standard method to derive such readings is Krifka's (1989) ** operator, defined in (6). The logical form corresponding to reading (5) is given in (7).

(4) Sue and Amy read 'Fried Green Tomatoes' and 'The L-Shaped Room'.

(5) a. Each of Sue and Amy read one of FGT and L, and each of the books was read by one of the women.

b. $\forall x \in S\&A$: $\exists y \in FGT\&L$: x read y &

$\forall y \in FGT\&L$: $\exists x \in S\&A$: x read y

(6) ** is that function: D<e,<e,t>> -> D<e,<e,t>> such that for any R:
[**R](y)(x) =1 iff R(y)(x) or
∃x1x2y1y2[(x=x1&x2) & (y=y1&y2) & **R(y1)(x1) & **R(y2)(x2)]

(7) <S&A, FGT&L> ∈ **λyλx[x read y]

This is fine for simple cumulative readings, whose existence is attested by (2a). But what about data like (2b), or example (8)?

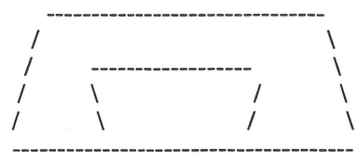
(8) a. The sides of the bookcase are parallel to the walls. [Heim (1994)]

b. <[[the sides_b]],[[the walls]]> ∈ **λyλx[x is parallel to y]

c. ∀x∈ [[the sides_b]]: ∃y∈ [[the walls]]: x is parallel to y &
∀y∈ [[the walls]]: ∃x∈ [[the sides_b]]: x is parallel to y

(8a) comes with the situation depicted in (9). It is generally judged to be false in this situation. However, The cumulative reading of (8a) given in (8b,c) would be true.

(9)



Intuitively, the sides of the bookcase are parallel to the wrong walls. It seems that we want to team up a side of the bookshelf with the wall next to it. Schwarzschild (1996) suggests that two-place pluralization is restricted by a contextually given relation. In our representation we would have (10a) rather than (8b). The relation would be provided by the visual information that is part of the context, and amounts to (10b). (10) is false in situation (9), as desired.

(10) a. <[[the sides_b]],[[the walls]]> ∈
**λyλx[<x,y>∈R & x is parallel to y]]

b. R = {<right_side_b,right_wall>, <left_side_b,left_wall>}

In example (11a) repeated from above, the quantificationally weak cumulative reading is made stronger by the relation introduced by the previous sentence. The analysis is given in (11b,c).

(11) a. Although the couples in our study were not married, the women showed aggressive behaviour towards the men.

b. <[[the women]],[[the men]]> ∈
**λyλx[<x,y>∈R & x aggressive to y]]

c. R = {<x,y>: x and y are members of the same couple}

(12) from Scha & Stallard (1988) is a final example, with context and analysis as indicated. Intuitively, (12a) is understood to mean that the frigates within one area are faster than the carriers in that area. Schwarzschild suggests that R in this example would team up frigates with carriers in the same area.

(12) a. (Context: Groups that consist of both frigates and carriers are sent to different areas all over the globe. Some areas might require a more efficient military presence than others.) The frigates are faster than the carriers.

b. <[[the frigates]],[[the carriers]]> ∈
**λyλx[<x,y>∈R & x is faster than y]

3. Salient Relations as Partitions

Let's collect the relations that would have to be salient in the relational plural sentences we have looked at.

(13) a. The frigates are faster than the carriers.
b. R={<x,y>: x is in the same area as y}

(14) a. Although the couples in our study were not married, the women showed aggressive behaviour towards the men.
b. R={<x,y>: x and y are in the same couple}

(15) a. The sides of the bookcase are parallel to the walls.
b. R={<x,y>: x is on the same side of the room as y}

All these relations are equivalence relations. Equivalence relations define a partition on the set they operate on, as defined in (17a) (example in (17b); partition is defined in (18)).

(16) R is an equivalence relation iff R is refelxive, symmetric and transitive.
R is reflexive iff ∀x∈D: <x,x>∈R
R is symmetric iff ∀x,y∈D: if <x,y>∈R then <y,x>∈R
R is transitive iff ∀x,y,z∈D: if <x,y>∈R and <y,z>∈R then <x,z>∈R

(17) a. $Part_R$ = {X: ∀x,y∈X: <x,y>∈R &¬∃z[<x,z>∈R & z∉X]}

b. R1={<x,y>: x is in the same area as y}
$Part_{R1}$ = {X: ∀x,y∈X: x is in the same area as y &
¬∃z[z is in the same area as x and z∉X]}

(18) Part is a partition of a set A iff
Part is a set of subsets of A
Every member of A belongs to some set in Part
{} is not in Part
for any X,Y ∈ Part: X∩Y={}

That is, the relation 'x is in the same area as y' can be seen as partitioning the set of ships according to area. Similarly, the relation 'x is a member of the same couple as y' can be seen to partition the set of people in the context into couples. (19) and (20) below represent an equivalent way of stating the meanings of these relational plurals, according to this change of perspective.

(19) ∀X[$Part_R$(X) -> the frigates in X are faster than the carriers in X]

(20) ∀X[$Part_R$(X) -> the woman in X showed ... towards the man in X]

Schwarzschild's theory does not predict that salient relations are limited to equivalence relations. Any relation that is made salient should be able to serve as a restriction. In (21) and (22) I try to make the non-equivalence relations in (21b), (22b) salient by mentioning them in the preceding discourse. These are not equivalence relations, and the readings that would result are unavailable.

(21) a. # The people who live in this house are all graduate students. They moved in one after another within a period of two years. The women like the men.

b. R={<x,y>: x moved in after y}

c. <[[the women]],[[the men]]>∈
**λyλx[x moved in after y & x likes y]

d. If a woman moved in after a man, the woman likes the man.

(22) a. # These five linguists followed immediately upon each other as department heads (have offices immediately next to each other). The syntacticians among them hate the phonologists.

b. R1 = {<x,y>: x was department head after y}
R2 = {<x,y>: x has an office immediately next to y's office}

c. <[[the synt.]],[[the phon.]]> ∈ **λyλx[<x,y>∈R & x hates y]

d. If a syntactician was department head immediately after a phonologist, the syntactician hates the phonologist.
If a syntactician has an office immediately next to a phonologist, the syntactician hates the phonologist.

At the same time, these relations can be made available by previous mention. (23) shows that they can be part of an E-type description.

(23) a. Every syntactician has an office next to a phonologist and invariably hates him.

b. the phonologist s/he has an office next to.

c. R = {<x,y>: x is a phonologist that has an office next to y}

On Schwarschild's theory, therefore, the absence of readings (22d) for (22a) is unexplained. We would expect a wider range of relations to be able constrain cumulation than we actually find. The partitional perspective on the data that do work, sketched above, suggests that instead of looking at the contextually provided information as a relation, we should look at it as a division into 'cases'. We then analyze the sentence as universal quantification over those 'cases'. The sentences we have looked at would be paraphrased as below.

(24) In each case/area, the frigates are faster than the carriers.

(25) In each case/on each side of the room, the wall is parallel to the side of the bookshelf.

(26) In each case/couple, the woman showed aggressive behaviour towards the man.

Implicit universal quantification over 'cases' is of course not new. Some relevant data that are outside the realm of plural predication are given in (27)-(30). The last two have been discussed as telescoping in the literature. In each example, we continue a discourse in a partitional way.

(27) The countries in our study are similar in a number of ways. There is a president, who is elected by the parliament. The parliament consists of...

(28) In each case/country there is a president ...

(29) Each degree candidate walked to the stage. He took his diploma from the dean and returned to his seat. [Roberts (1987)]

(30) In each room there was a cat and a goldfish. The goldfish dived. The cat caught it. [Stenning (1978) from Roberts (1987)]

I propose to analyze the relational plural data in terms of universal quantification to capture the limitation to partitional interpretations. Turning this idea into a semantic analysis requires giving concrete answers two questions: How does the universal quantification come in, and what variable is quantified over (or, what are cases)? I will make a suggestion for both below that is as yet very preliminary.

The element common to all the data I have looked at is that the context is in some way suitable to partition a situation into a set of distinct relevant subsituations. If we universally quantify over such subsituations, the interpretations we get roughly fit the schema in (31) (I choose to talk about situations here; the alternative would have been to talk about eventualities. I do not think this makes

a difference for my analysis at this point: my 's' variables should be either minimal situations or eventualities).

(31) AR_SB iff $\forall s'[s' \leq_C s \rightarrow$
R holds in s' between the part of A in s' and the part of B in s']

$s' \leq_C s$ iff C(s') and $s' \leq s$; C is the set of contextually relevant situations.

Quantifying over situations is slightly more tolerant then quantifying over the cells of a partition of individuals directly since the context might make a division into subsituations salient without there being an equivalence relation available. A relevant example is (32) (due to Irene Heim (p.c.)). The situation suggests a division into minimal pot-lid-pair situations, even if the relation we would suggest to be salient (in italics in (32b)) is not an equivalence relation.

(32) a. The lids do not fit onto the pots.

b. The lids do not fit onto the pots that they are *lying on top of.*

c. $\forall s'[s' \leq_C s \rightarrow$ the lid in s' does not fit in s' on the pot in s']

The data in (21) and (22) do not make a partition into relevant subsituations salient, while equivalence relations obviously do, so this seems to be the correct distinction.

My suggestion concerning the way universal quantification over subsituations gets in there is that it comes about as part of a pluralization operation, not as an independent universal quantifier. A relevant example is (33a), to be considered in the same context as (2b). A good formalization looks like (33c), not like (33b).

(33) a. The five women showed aggressive behaviour towards the five men.

b. $\forall s'[s' \leq_C s \rightarrow$ the five women in s' showed aggressive behaviour towards the five men in s']

c. $\forall s'[s' \leq_C s \rightarrow$ 'showed aggressive behaviour towards' holds in s' between the part of the five women in s' and the part of the five men in s']

We need to look at parts of our plural individuals at the same time as we consider parts of the situation. I propose that this is an instance of polyadic pluralization which affects two individual arguments and the situation argument of a relation simultaneously. We can straightforwardly define the generalization of ** to *** as in (34) (see also Sternefeld (1998), Sauerland (1998)). The correct truth conditions for our data can be captured by (35), (36).

(34) *** is that function: D<e,<e,<s,t>>> -> D<e,<e,<s,t>>> such that for any R: [***R](y)(x)(s) =1 iff R(y)(x)(s)
or $\exists x1x2y1y2s1s2[(s=s1 \& s2) \& (x=x1 \& x2) \& (y=y1 \& y2) \&$ ***R(y1)(x1)(s1) & ***R(y2)(x2)(s2)]

(35) <A,B,s> ∈ ***λyλxλs'[C(s') & C(x) & C(y) & R(y)(x)(s')]

(36) <A,B,s> ∈ ***λyλxλs'[C(s') & C(x) & C(y) & R(x)(y)(s')] iff
$\forall s'[s' \leq s \; \& \; C(s') > \exists xy[C(x) \; \& \; C(y) \; \& \; x \leq A \; \& \; y \leq B \; \& \; R(y)(x)(s')] \; \&$
$\forall x[x \leq A \; \& \; C(x) \rightarrow \exists s'y[C(s') \; \& \; C(y) \; \& \; s' \leq s \; \& \; y \leq B \; \& \; R(y)(x)(s')] \; \&$
$\forall y[y \leq B \; \& \; C(y) \rightarrow \exists s'x[C(s') \; \& \; C(x) \; \& \; s' \leq s \; \& \; x \leq A \; \& \; R(y)(x)(s')]$

I adopt here Schwarzschild's (1996) suggestion that we always divide pluralities into their salient parts. In (35), (36) this applies to both individuals and

situations via the requirement that they be a member of C. C is a salient cover or partition. This derives the appropriate interpretations for our data.
I conclude that the data that have been viewed as arguing for a contextually salient relation in relational plurals actually show that pluralization affects the situation/event argument of the relation, and that the pluralization is evaluated relative to a contextually provided division into subsituations. Part/whole structures of events/situations have been assumed for a number of reasons (see e.g. Lasersohn (1995) and references therein), and I extend Schwarzschild's proposal about contextually provided partitions from individuals to situations. The parallel I see to the data in (27)-(30) is that we make use of a salient partition of a complex situation into subsituations.

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Incorporation as Unification

Ágnes Bende-Farkas*
IMS, Stuttgart University
e-mail: agnes@ims.uni-stuttgart.de

Summary: This paper proposes an analysis of a particular Definiteness Effect construction, that involving the light verb *have* as found in e.g. *John has a sister*. The analysis is based on the notion of term unification, which has played an important role in computer science and computational linguistics but, to my knowledge, hardly within formal semantics. According to term unification, the verb *have* and ist object phrase both introduce a predicational "term" consisting of a predicate and its arguments. Combining verb and object phrase involves unifying these two terms. When unification fails for some reason, the combination is unacceptable. The analysis is capable of extension to other Definiteness Effect constructions, including those involving "light" verbs in Hungarian.

1 Incorporation

In Van Geenhoven (1996) the author proposes the following treatment of "incorporation constructions" – constructions in which a verb and a nominal form one unit, with the effect that there is something of the kind denoted by the nominal which satisfies the relevant argument position of the verb. Such constructions are found in West-Greenland Eskimo, which van Geenhoven discusses, and many other languages besides. Incorporating verbs, according to van Geenhoven, have entries of the following forms:

(1) $a.\ TVs:\ \lambda P.\lambda x.\exists y.[V(y,x) \wedge P(y)]$ $b.\ IVs:\ \lambda P.\exists x.[V(x) \wedge P(x)]$

Here P is a variable of type $\langle e,t\rangle$, which gets instantiated by a common noun phrase (i.e. a predicate of type $\langle e,t\rangle$ when the verb is combined with a noun). The form of the entry is then responsible for the existential interpretation of the combination.

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Van Geenhoven proposes that an analogous analysis is also applicable to certain to "Definiteness Effect" constructions, which involve an NP position that may be occupied by indefinite NPs but not by definite or quantificational NPs, and in particular to constructions involving the English "weak" verb *have* and its counterparts in many other languages. Typical instances of weak *have* are found with object phrases whose head nouns are relational, such as *wife*, as in *Clyde has a wife*. *Have* as it is used in this sentence is called weak, because the actual relation that the sentence conveys between subject and object is not expressed by the verb itself but rather by the object noun. That such uses of *have* are subject to the Definiteness Effect can be seen by comparing the continuations (2a) and (2b).

(2) Clyde married Bertha. (a) So now he has a wife.
(b) So now he has her. (??)

(2a) can be paraphrased as *Now he is married*, but (2b) cannnot be paraphrased as *Now he is married to her.*

In order to apply the analysis in (1) to weak *have*, indefinites like *a wife* have to be taken to contribute to the verb-object construction a nominal (i.e., in this case, just *wife*). So, it is necessary to argue for some kind of type coercion here Partee (1987)). This is a complication, moreover, which equally arises when this strategy is applied to other Definiteness Effect constructions which accept full indefinite NPs, rather than, or as well as, bare nominals. It is clear, however, that in general this won't be enough to arrive at a fully satisfactory analysis. For there are significant differences between the various incorporation and Definiteness Effect contructions across languages. In particular, some such constructions allow the verb's object to act as antecedent to subsequent anaphoric pronouns (West Greenland Eskimo, Mohawk), whereas others do not (Hindi is one of these, see e.g. Dayal(1998)). Especially intriguing in this regard are the so-called "light" verbs of Hungarian (Szabolcsi (1986)). This is a substantial class of verbs which all show the Definiteness Effect, and which can be combined both with bare nominals and with full indefinite NPs. Pronominalization is possible when the object is a full NP, but not when it is a bare nominal:

(3) *a.* János macskát talált. ???Fekete volt.
John cat-Acc found. ???Black was
"There was a cat-finding event by John. ?It was black."
b. János talált egy macskát. Fekete volt.
John found one cat-Acc. Black was.
"John found a cat. It was black."

Evidently, a differentiated analysis of the different types of Definiteness Effect constructions is needed in order to explain these further differences. In the present paper an analysis for English weak *have* is proposed, which can be extended to account naturally for some of those differences, including the puzzle presented by Hungarian light verbs. The proposal borrows from Partee (1999a) and earlier work by the same author, but adds some elements of its own.

2 Unification

According to this proposal, then, the light verb introduces a higher order (relational) discourse referent. Provisionally this is taken to be of a pronominal character, needing to be matched to/unified with a property (with a relation in the case of *have*). This pronominal character distinguishes *have* from *own*, which can be seen from the difference between *John has a sister* and *John owns a sister.*[1]

Have is assigned the following entry in a space-saving linear notation, where DRSes are ordered pairs of a universe (set) and a condition set: $\langle U_K, Con_K \rangle$.

(4) $\langle \{s, \alpha, \beta\ R\}, \{R(s, \alpha, \beta)\} \rangle$

In (4), $R(s, \alpha, \beta)$ means that s is a state of affairs to the effect that α stands in the relation R to β.

The 'pronominal' status of R is to be understood in the following way: the condition "$R(s, \alpha, \beta)$" is to match a parallel condition supplied by the object NP. We assume, along with other work on bottom-up, compositional DRT (Kamp–Reyle t.a.) that the indefinite contributes a representation of the form (5):

(5) $\langle \{s', \gamma\}, \{s' : \langle \{\delta\}, \{Sister(\delta, \gamma)\} \rangle\} \rangle$

(5) says that s' is the state of γ being a sister of δ. δ is an implicit argument of *Sister*, because it is usually inaccessible to pronominal anaphora on its own, like the implicit arguments of compounds (Heim (1982)).

Combining (4) with (5) involves matching of the conditions $R(s, \alpha, \beta)$ $Sister(s', \delta, \gamma)$. This is understood in the sense of term unification. The two 'terms' unify if (i) $R(^{-1}) = Sister$, and (ii) the arguments match pairwise: $s = s', \alpha = \delta, \beta = \gamma$. (ii) is familiar from standard DRT, but (i) requires elucidation. In a simplified version of the analysis, R is an unconstrained 2-place relation variable. According to the present version, *have* might not be said to be "weightless" anymore. So, $R = Sister$ amounts simply to matching subject and object.

Applying the required (well-known) DRT-rules, we get the following DRS for the sentence *John has a sister*:

(6) $\langle \{n\ s\ s'\ \alpha\ \beta\ R\ \gamma\}, \{n \subseteq s', John(\alpha), R(s, \alpha, \beta), R = Sister, \beta = \gamma\} \rangle$

This is still not the entire picture, however, because *have* is not completely weightless. That it has some contribution of its own, and does constrain to some extent the set of possible relations, is shown by the oddity of *John has a divorcée*, intended to convey that John is divorced. The set of possible relations that can be matched to *have* is

[1] In this paper we concentrate on the basic, "light" meaning of *have*. We are aware of the differences between "light" *have* and "small clause" *have*, such as *John has his coat under the bed*, or between *have* of possession and cases like *John has Mary's cats now*, meaning that Mary's cats are with John for the time being.

some subset GEN of all possible 2-place relations. According to this version of the theory, *John has a sister* is acceptable because $Sister \in GEN$.[2]

Non-relational nouns such as *car* are assumed to be coerced into relational nouns, as suggested for genitive constructions in Jensen–Vikner (1994) and Partee (1999b). But then this means, as it should, that (part of) the meanings of their relational variants (say, Car' in the case of *car*) are in the set GEN. They can be given entries like the following:

(7) *a. a cat-of:*
b. $\langle\{s,x\},\{s{:}\,\langle\{\alpha\},\{cat(x),R_G(\alpha,x)\}\}\rangle$
c. $\langle\{s,x\},\{s{:}\,\langle\{\alpha\},\{\textit{cat-of}(\alpha,x)\}\}\rangle$

The common trait of (7b–c) is the introduction of a second (implicit) argument (α), with which the relevant discourse referent stands in some (GEN-)relation. (7c) incorporates the relevant relation in its meaning, whereas (7b) is more explicit. R_G in (7b) is one of the relations typically expressed by the possessor relation. R_G is not pronominal, unlike of *have* itself.

We take GEN to be closed under union or summation. This is motivated by examples like the following:

(8) John has a sister and two cats

The conjoined NP is taken to introduce a collective discourse referent X which is the sum of the two conjuncts. Likewise, the relation contributed by X is the smallest relation in GEN that comprises *Sister* and *Cat(s)-of*.

3 The Definiteness Effect with Have

On this approach, the object of *have* predicts the right kind of properties for the Definiteness Effect.

Like NPs in *there*-insertion contexts, the object of *have* is to introduce a new discourse referent (McNally (1998) a.o.). This is ensured by the requirement (implicit in unification) that the relevant discourse referent should be unbound, where binding includes anaphoric binding and anchoring. Discourse-new definites may be admitted as objects of *have*, precisely because they are not bound to previous context:

(9) John has the smartest cat I know

[2] *Have* may not simply be conflated with the contribution of the Genitive, at least not in English. The set of relations expressible with light *have* seems to be a proper subset of those expressible by means of the Genitive, as seen from the following contrasts. (*Hundertwasser's house* is taken to mean a/the house designed by H.)

(*i*) *a. #Hundertwasser has a house in Stuttgart*
b. Yesterday we visited Hunderwasser's house in Stuttgart

(*ii*) *a. Virginia Woolf has a manuscript/#a hat in this museum*
b. This museum keeps Virginia Woolf's manuscripts/hats

Indefinites containing a presupposition, as in *John has his cat*, are excluded for the same reason as anaphoric definites.

Strong "quantifying" NPs are excluded from the object position of *have* for two (closely related) reasons. First, *have* provides a predicational frame, so to speak, which expects a term-type object. A quantificational NP like *every sister* simply does not "fit" into that frame, and there is no access to the free variable required by *have*.

Second, if one starts out from the quantifier, and tries to introduce *have* in its nuclear scope, several things can happen. Even if we take (10a) as grammatical, and do want to get something, the best is an uninformative reading.

(10) *a.* ∗John has every sister:
b. $\langle\{j,n\},\{\forall x.\langle\{s,x\}\{n\subseteq s,s{:}\,\langle\{\beta\},\{x\textit{Sister-of}\beta\}\rangle\rangle,$
$\langle\{s',R,\alpha,\},\{n\subseteq s',R\in GEN,s'{:}\,jR\alpha\}\rangle\}\rangle$

If we assume that unification can be performed for (10b), this yields the tautology reading familiar from Barwise and Cooper: *every sister of John is a sister of John.* But unification should not be possible in this case: *have* is taken to expect a unifier in its local context.[3]

For the same reason, that is, because *have* expects a local unifier, only narrowest scope is possible under operators, or in attitude contexts, in sentences like *John thinks that Mary has a sister*, or *Whenever we visited him, John had a cat.*

Mutatis mutandis, the same holds for object NPs with constituent negation: within the scope of negation, *have* and its object are in each other's local contexts. So, a sentence like *John has no sisters* will be paraphrased as *It is not the case that John has a sister.*

4 Hungarian Light Verbs

Hungarian light verbs are amenable to the same kind of analysis that has been proposed for English *have*. One important difference with English *have* is that typically, Hungarian light verbs provide more content.

For instance, the lexical entry for the verb *talál* 'find' is said to contain an event description (there is a finding event by the agent), and a consequent state. It is the description of the consequent state that contains a higher order discourse referent awaiting unification. This is based on the intuition that the consequent states of these verbs are not hard-wired in the lexicon, so to speak, but are contributed to a large extent by the Theme argument, iff it has the required properties.

(11) *a. talál* 'find':
b. $\langle\{ec,\alpha\},\{ec{:}\,\langle\{e,s,P,\beta\},\{e{:}\,\alpha find\ \beta,s{:}\,P(\beta)\}\rangle\}\rangle$

[3] For reasons of space, a full account of this will be provided in the longer version of this paper.

(11b) contains a higher order discourse referent P which needs to be unified with the property contributed by the internal argument. In the case of (3b), for instance, P is unified with *cat*. The first-order discourse referent β for the internal argument is introduced internally to the event description. This way, β on its own is inaccessible to pronominal anaphora.

Hungarian bare nominals are not taken to introduce discourse referents, at least, not accessible ones. Hence, in the case of (3a), the internal argument β remains unmatched and thus inaccessible. If the object of *talál* is a full NP, as in (3b), it introduces a discourse referent at the appropriate DRS level, which is then accessible for anaphora. Thus the difference between (3a) and (3b) is seen to follow from the the different semantics for bare nominals and full NPs, eliminating the need to stipulate an ambiguity for the incorporating structure itself.

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Questions as First Class Citizens

Martin van den Berg
FX Palo Alto Laboratory

1 introduction

In this paper we use Dynamic Quantifier Logic (van den Berg 1996) combined with the Linguistic Discourse Model (Polanyi and Scha 1983, Polanyi 1988, van den Berg and Polanyi 1999) and to give a formal treatment of questions and answers in dynamic semantics. We give a treatment of wh-phrases that parallels generalized dynamic quantifiers. Specifically, we introduce an operator ? that functions as a quantifier, and which has the correct semantics to interpret a wide variety of question types. With respect to the dynamic logic, the operator ? functions similarly to other quantifiers, and the right discourse anaphoric behavior of questions will follow directly from general properties of dynamic quantifiers. Our approach, which stays close to the account of questions and answers in (Groenendijk and Stokhof 1984), implements incremental interpretation following the Linguistic Discourse Model.

The treatment of questions as equivalence relations between possible worlds (functions from possible worlds to propositions, the latter regarded as sets of possible worlds) taken in Groenendijk and Stokhof (1984) poses a problem for dynamic theories of meaning as has been discussed earlier in the literature (Groenendijk ms, van Rooy 1999). The meanings of questions are of a different logical type than the meanings of declarative sentences.

Dynamic logic relies on the reinterpretation of what it means to be a proposition from a set of worlds (in which the proposition holds) to a relation between an input information state and an output information state (cf. Groenendijk and Stokhof 1991, van Benthem 1996, van den Berg 1996). It is through this relation that all anaphoric information is encoded.

This suggests is an obvious dynamic interpretation of questions: reinterpret what it means to be a proposition and interpret questions as functions from possible worlds to such dynamic propositions. In this abstract, we will argue that this is exactly the right way to interpret questions. The most important problem to be solved to achieve this is the fact that questions in this interpretations are functions from worlds to dynamic propositions, rather than being themselves dynamic propositions. Such an interpretation of questions cannot adequately account for the fact, that questions seem to behave with respect to picking up and introducing anaphora in the same way as declarative sentences:

(1) *I see you have* a^1 *new painting. Who did you buy* it_1 *from?*

(2) *Which woman was* $Bill^2$ *talking to just now?* He_2 *was talking to* his_2 *sister.*

We will show that when an adequate account is given of the way expressions in a discourse add to our information about the world that the discourse describes, this apparent conflict is resolved.

This extended abstract consists of four main sections. In section 2 we give a simplified version of the positive fragment of the dynamic plural logic defined in (van den Berg 1996) and sketch how this can be used to give a general treatment of generalized quantifiers. in section 3 we give a simple treatment of questions in terms of this. In section 4 we give a short overview of the Linguistic Discourse

Model, concentrating on its impact on the matters at hand. In section 5 we briefly list a number of issues that are discussed in the full paper, but are left out of this extended abstract to simplify and shorten things. We finish with some conclusions.

2 Dynamic Quantifier Logic

In this abstract, we will use a simplified version of the logic defined in (van den Berg 1996). This is a dynamic logic in which formulas are interpreted relative to sets of partial assignments to be able to encode plural discourse referents. The following gives some useful definitions.

(3) The set G, restricted to certain subsets:
$G|_{x\in D} := \{g \in G \mid g(x) \in D\}$, $G|_{x\notin D} := \{g \in G \mid g(x) \notin D\}$,
$G|_{x=\star} := \{g \in G \mid g(x) = \star\}$, $G|_{x\neq\star} := \{g \in G \mid g(x) \neq \star\}$.

(4) The value G assigns to variable x is defined by: $G(x) := \{g(x) \mid g \in G|_{x\neq\star}\}$

(5) We assign x a value $G[x := D] := \{h \mid \exists g \in G : h \approx_x g \;\&\; h(x) \in D\}$, where $h \approx_x g$ iff $\forall y \neq x\ g(y) = h(y)$

the dynamic logic is now defined as follows[1].

(6) $G[P(x,\ldots,y)]H \iff \langle G(x),\ldots,G(y)\rangle \in \mathcal{I}(\mathcal{P}) \;\&\; \mathcal{G} = \mathcal{H}$

(7) $G[\phi \wedge \psi]H \iff \exists K : G[\phi]K \;\&\; K[\psi]H$

(8) $G[\varepsilon_x]H \iff \exists D : H = G[x := D]$

Using this logic, we can now give a general definition of a dynamic quantifier. This is most easiest explained using an example.

the following definition gives one of the readings of *exactly four women gathered* (cf. van der Does 1982)[2]

(9) $\exists W \subseteq \mathsf{MAX}(\mathbf{woman})\exists E \subseteq \mathsf{MAX}(\mathbf{gather})|W \cap E| = 4$

(10) $\exists W \subseteq \mathsf{MAX}(\mathbf{woman})\exists E \subseteq \mathsf{MAX}(\mathbf{gather} \cup \wp\{W\})|W \cap E| = 4$

Where, **women** is the set of all sets of women, **gather** is the set of all sets of gatherers, W, E are variables over sets of entities and MAX is an operator that restricts a set of sets to its maximal elements relative to inclusion.

Note that, given conservativity, these two are the same. Both can be reinterpreted directly in dynamic logic. We choose (10) as the basic definition, because this will give us Y as a discourse referent referring to the women that entered.

(11) $\varepsilon_{x'} \wedge \mathsf{M}_x(\mathbf{woman}(x')) \wedge \varepsilon_x \wedge x \subseteq x' \wedge \mathsf{M}_{x\subseteq x'}(\mathbf{enter}(x)) \wedge 4(x', x)$

where M is a dynamic counterpart of the maximization operator (cf. van den Berg 1996 for details).

We can now give dynamic counterparts of quantifiers as follows

(12) $\mathsf{Q}x \subseteq y(\phi(x),\psi(x)) := \varepsilon_{x'} \wedge x' \subseteq y \wedge \mathsf{M}_{x'\subseteq y}(\phi) \wedge \varepsilon_x \wedge x \subseteq x' \wedge \mathsf{M}_{x\subseteq x'}(\phi(x))$

[1] We do not define negation. The reason is that a useful dynamic negation can only be defined over a partial logic, complicating all definitions in ways that are irrelevant for the current discussion. We will discuss this in the full paper.

[2] Other static definitions can be made dynamic in similar ways.

In our approach, a discourse consists of a sequence of atomic units, called *basic discourse units* (BDUs). Every unit encodes an atomic proposition. For discourse purposes, it makes sense to think of the set of possible worlds corresponding to such a proposition as a partial (possible) world[3]. The logical representation of the unit explicitly quantifies over variables that range over possible worlds. In the case of event clauses, these partial worlds have the special property of characterizing an event, with the usual relations defined on them. Let's illustrate this idea using (13), with variables e_i ranging over partial worlds.

(13) A man walked to the bench. He sat down.

(13′) $\exists x_0 \subseteq e_s(\mathbf{sing}(x_0) \wedge \mathbf{man}(x_0), \exists e_0(\mathbf{sing}(e_0), \mathbf{wttb}(x_0))$
$\wedge\exists x_1 \subseteq x_0.(\mathbf{sing}(x_1), \exists e_1 \subseteq e_s(\mathbf{sing}(e_1) \wedge e_0 \leq_{\mathsf{next}} e_1, \mathbf{sitdown}(x_1))$

The first part binds x_0 to a man that walks in the direction of a bench, and e_0 to an event of that kind. Note there could be more than one man satisfying this and consequently more than one event. The second sentence binds x_1 to the same man (by being a subset of x_0 that consists of 1 element), claiming that that man sat down, and e_1 to the event of sitting down. Furthermore, both events e_0 and e_1 are required to be part of some larger sum-partial-world e_s. This last condition is to make sure that the two events are compatible[4].

3 Simple Questions

Within the formalism we defined above, defining what it means to be a question is simple enough. We can define a pseudo-quantifier ?, which will encode the wh-part of the question. Given the definition of generalized dynamic quantifiers, this definition looks almost too simple.

(14) $?x \subseteq y(\phi(x),\psi(x)) := \varepsilon_{x'} \wedge x' \subseteq y \wedge \mathsf{M}_{x'\subseteq y}(\phi(x') \wedge \varepsilon_x \wedge x \subseteq x' \wedge \mathsf{M}_{x\subseteq x'}(\psi(x))$

This binds x to the largest set satisfying $\phi(x)$. Note that this set will in general not be unique. Using this, we can give an interpretation of examples (1) and (2) above.

(1) *You have a[1] new painting. Who did you buy it$_1$ from?*

(1′) $\exists x(\mathbf{pntg}(x), \exists e_0 \subseteq e_s(\mathbf{sing}(e_0), (e, \mathbf{have}(e_0, x))))$
$\wedge ?y_1(\mathbf{person}(y_1), \exists e_1 \subseteq e_s(\mathbf{sing}(x_1), \exists x_1 \subseteq x_0(\mathbf{sing}(x_1), \mathbf{ybf}(e_1, x_1, y_1))))$

Because ? is defined as a quantifier, it is transparent for anaphoric reference, so no special problems relative to anaphoric binding arise. There is, however, another issue that does need to be addressed: what is the origin of e_s. For the moment, we will assume that e_s can be any partial world that both e_0 and e_1 are part of that is compatible with our information so far.

3.1 Groenendijk and Stokhof 1984

This definition comes very close to the original interpretation of a question that Groenendijk and Stokhof gave in 1984. The main difference is that this definition is contextualized: for discourse initial questions, the meanings coincide.

To illustrate this, look at the following question and interpretation in initial state G, where we left out all anaphoric links to stress this is discourse initial:

[3] We will discuss the reasons for this view somewhat more below.

[4] In fact, this sum world is very likely to be important in determining what it means to be the next event. This is an issue, however, that is outside the topic of this paper.

(15) Which dog entered?
$G[?x(\mathbf{sing}(x) \wedge \mathbf{dog}(x), \exists e(\mathbf{sing}(e), \mathbf{enter}(e,x)))]H$

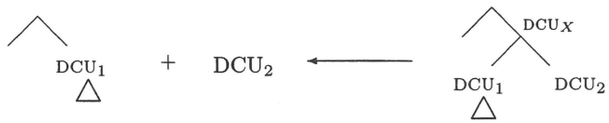
After this $H(e)$ will be some partial world in which one dog entered, and $H(x)$ will be that dog[5]. Partial worlds correspond to sets of possible worlds, so for different sets $H(x)$ of dogs (i.e. different answers), we are given a different set $H(e)$ of possible worlds.

Given this correspondence, all of Groenendijk and Stokhof's treatment of questions and answers can be transplanted on this dynamic approach.

4 Discourse Grammar

The formalism above suggests that the units of discourse relate to the preceding context in two ways. First of all, they build up a more and more precisely defined partial world, like e_s above, and second, the relate anaphorically to preceding units in the same narrative, enumeration, etc., like e_0 above. These two aspects originate in different stages of the construction of the discourse.

The Linguistic Discourse Model (LDM) is designed as a discourse parser designed to incrementally construct a meaning representation of the input discourse as a tree. Consecutive units are attached at the right edge of the tree.



The combination of DCU_1 and DCU_2 can either be a *coordination*, a *subordination* or a *binary construction*[6].

Here I will not discuss binaries, but illustrate the other two with simple example.

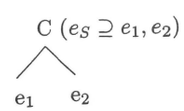
(16) (a) *John came in.* (b) *He put the groceries on the table.*

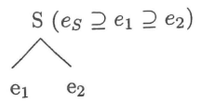
(17) (a) *John came in.* (b) *He was screaming.*

Example (16) illustrates a coordination of events, in this case forming a list called a *narrative*. (16a) introduces an event e_1, and (16b) introduces a second event e_2. Because this is a coordination, the event introduced by the two together is the combination of these two, the smallest relevant event e_s that contains both these. In the case of (17), a subordination of the kind elaboration, "the sum" event is essentially the subordinating event e_1, and the elaborating (17b) is interpreted in the context of that event:

[5]This example was chosen to be singular for a reason. The plural case will nly work right within the full logic. In particular, we need the fact that that logic is partial to account for negative answers were there are no dogs. This is discussed in the full paper.

[6]The input DCU will be Coordinated with a node present on the right-edge of the tree if it continues a discourse activity (such as topic chaining or narrating) underway at that node. The input DCU will be Subordinated to a node on the right-edge of the tree if it elaborates on material expressed at that node or if it interrupts the flow of the discourse completely. The input DCU will be Binary-attached to a node if it is related to that node in a logical, rhetorical or interactional pattern specified explicitly by the grammar. We refer to Polanyi (1988), Polanyi and Scha (1983) and Polanyi and van den Berg (1996) for more details about the LDM.





We will now discuss how to formalize this informal idea.

With the LDM/DQL approach, units are given meanings that themselves do not contain anaphoric referents. all contextual information is transported through context set restrictions on the quantifiers, which are written as $\exists x \subseteq y$ (cf. van den Berg 1996). This also holds for the variables referring to partial worlds. To achieve this, every sentence is considered to introduce two discourse referents to partial worlds. One which is supposed to encode the sum of information about the partial world and one that encodes the specific contribution of the unit itself[7]. Take example (16) above. The meanings of (16a) and (16)b are ($R\bullet$ denotes a placeholder for relations that are filled in by the discourse grammar):

(16) (a) $\exists e_0^s R \bullet (\mathbf{sing}(e_0^s), \exists x_0 R \bullet (\mathbf{j}(x_0), \exists e_0 R \bullet (e_0 \subseteq e_0^s \wedge \mathbf{sing}(e_0), \mathbf{c}(e_0, x_0))))$

(16) (b) $\exists e_1^s(\mathbf{sing}(e_1^s), \exists x_1 \subseteq \bullet(\mathbf{sing}(x_1), \exists e_1 R \bullet (e_1 \subseteq e_1^s \wedge \mathbf{sing}(e_1), \mathbf{pgt}(e_1, x_1))))$

When these two are coordinated, the resulting meaning in the coordination node is:

(16) (a+b) $\exists e_0^s(\mathbf{sing}(e_0^s), \exists x_0 R \bullet (\mathbf{j}(x_0), \exists e_0 R \bullet (e_0 \subseteq e_0^s \wedge \mathbf{sing}(e_0), \mathbf{c}(e_0, x_0))))$
$\wedge \exists e_1^s \supseteq e_0(\mathbf{sing}(e_1^s), \exists x_1 \subseteq x_0(\mathbf{sing}(x_1), \exists e_1 \geq_{\text{next}} e_0(e_1 \subseteq e_1^s \wedge \mathbf{sing}(e_1), \mathbf{pgt}(e_1, x_1))))$

In a similar way, the partial descriptions of the world are integrated into a more and more complete description of the world of the discourse.

This gives a way of more explicitly discussing whether in a certain context something is a valid question or not. Given a partial description of the world, a question will extend this with possible extensions of that world, with possible answers. Following Groenendijk and Stokhof, a question is a valid question if there is more than one possible extension to the world, i.e. more than one non-equivalent set of possible worlds that gives a possible answer.

5 Other Issues

Because of the short length of this extended abstract, a large number of issues could not be addressed that are relevant for the above discussion. Some of these have already been mentioned before. The first few relate to simplifications made to the logical formalism. In the full paper, we will be using the full logic of van den Berg 1996.

- Negation was left out of the definitions of the logic, because a good definition of negation in a dynamic context requires the logic to be partial, severely complicating the definitions.
- We only discussed collective quantification here. One problem with that is that it makes it very hard to discuss empty answers like *noone did*, to questions like *Who came in.* Distributive quantifiers allow for such answers (essentially, because theuniversal quantifier, used to define distributivity, does not have existential import).

[7]This is similar to the way quantifiers over entities introduce two referents, one referring to the restriction of the quantifier (the CN-anaphor) and one to the actual entities introduced (the normal anaphor).

- An issue relating to distributivity is variable entanglement. The value-range of one variable can be dependent on the range of another in a skolem function like manner. this property helps to explain questions with more than one wh-phrase, and certain questions with embedded quantifiers which need a paired-list answer.

Other issues discussed in the full paper are

- A question introduces a referent that is an extension to the current partial world. However, this referent does not constitute a real piece of information about the world of the discourse. Only the answer gives such information. As such, a question is very similar to a modal subordination. An extension to the world, compatible with the world described so far, but in its own modal space, is introduced and a later sentence (the answer) is interpreted in its context.

- this issue leads to the general question what the precise discourse grammar rules are that guide the incorporation of the question and its answer into the discourse structure.

6 Conclusions

Given the right kind of formalization of dynamic semantics, formalizing questions is not that too difficult. In the full paper, we discuss how essentially all of Groenendijk and Stokhof's theory can be incorporated, without sacrificing any dynamic properties. We show that questions really are first class citizens, with formal properties not unlike the other units of discourse and that it is the discourse rules that, in the end, determine what it means to be a question. It is those rules which will resolve variables over partial worlds one way or another, determining whether the world described in the unit adds directly to the world the discourse is building up (in the case of declaratives) or whether that world is only added potentially (in the case of questions), needing an answer to "integrate" it to the world of the discourse.

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A New Probability Model for Data Oriented Parsing[1]

Remko Bonnema ILLC — Paul Buying AI, UVA — Remko Scha ILLC

Background *Data oriented parsing* (DOP) (Scha, 1990) is a probabilistic approach to natural language interpretation and disambiguation, which differs significantly from previous attempts in this direction. Earlier *probabilistic grammars* were probabilistically enriched competence grammars; the data oriented approach, however, defines a person's language by a stochastic process which recombines structures that are extracted from a representation of the person's past language experience (i.e., a corpus of utterances with syntactic/semantic annotations).

Data oriented language processing is usually implemented as an extremely redundant *stochastic tree substitution grammar* (STSG). The substitutable trees employed by this grammar are simply all the fragments that can be extracted from the corpus. The substitution probability of a tree of a particular category is estimated as the probability of sampling it from the collection of all fragments of the same category that are extracted from the total of all corpus trees (Bod, 1993).

Preliminaries Let G be a CFG-grammar and let $\alpha_1, \ldots, \alpha_k$ be arbitrary derivation trees or *parse trees* of G. If A is a non-terminal, we call the parse tree ${}_A(\alpha_1 \cdots \alpha_k)$ a *fragment*. If every α_i is lexicalized, ${}_A(\alpha_1 \cdots \alpha_k)$ is called a *constituent tree* or a *constituent*.

A parse tree τ is said to *start* a parse tree τ' iff there exists a CFG-derivation $\tau = \alpha_1 \Rightarrow \cdots \Rightarrow \alpha_n = \tau'$. If a fragment α starts a parse tree τ we call α an *initial fragment* of τ. For a parse tree τ we define $\sigma(\tau)$ to be the set of all initial fragments of τ. If τ has no initial fragments, we let $\sigma(\tau) = \varnothing$. A parse tree may also *occur* in a parse tree according to the following definition. (1) τ' occurs in τ, if τ' starts τ; (2) τ' occurs in $\tau = {}_A(\alpha_1 \cdots \alpha_i \cdots \alpha_k)$ if τ' occurs in α_i.

For two parse trees τ' and τ, we define $f(\tau'; \tau)$ to be the number of instances of τ' that occur in τ. If τ' does not occur in τ, we let $f(\tau'; \tau) = 0$. For a fragment or constituent τ we use $r(\tau)$ to denote the (root) label or *category* of τ, such that $r({}_A(\alpha_1 \cdots \alpha_k)) = A$. Let $N(\tau)$ refer to the number of non-root symbols of a constituent τ that are non-terminal.

Throughout this text we assume that a *corpus* or *treebank* $\mathcal{T}$ is given as a collection of constituent trees $\tau_1, \ldots, \tau_n$. The term *collection* is used to emphasize the property that $\tau_i = \tau_j$ may hold for $i \neq j$. Given a treebank $\mathcal{T}$, we define $\mathcal{C}$ to be the set of constituents occurring in $\tau \in \mathcal{T}$. We use $\sigma[\mathcal{C}] = \bigcup_{i=1}^{n} \sigma(\tau_i)$ to refer to the set of all initial fragments of $\mathcal{T}$. We sometimes use a non-terminal A as a subscript of the set $\mathcal{C}$ to denote the restriction of the set to constituents of category A. Analogous to the definition above, $\sigma[\mathcal{C}_A]$ then denotes the set of all initial fragments of $\mathcal{C}_A$.

The total number of instances of a parse tree τ in a corpus $\mathcal{T}$ is denoted $f(\tau) = \sum_{i=1}^{n} f(\tau; \tau_i)$. Given a parse tree τ of category $r(\tau)$, the *relative occurrence frequency* or *relative frequency* $F(\tau)$ of τ in $\mathcal{T}$ is defined as $F(\tau) = f(\tau)/f(r(\tau))$.

The Classical DOP Model To generate a new sentence from fragments present in the corpus, the DOP model defines the composition operation of *leftmost substitution*, a partial function on pairs of fragments. The composition of fragments α and β, written as $\alpha \circ \beta$ is defined iff the label of β is identical to the leftmost

[1] An extended version of this article is also available (Bonnema, Buying and Scha, 1999) as Technical Report PP-1999-26, Institute for Logic, Language and Computation, Amsterdam, The Netherlands, 1999.

non-terminal of α. A *leftmost derivation* $\alpha_1 \circ \cdots \circ \alpha_n$ of a constituent τ starts with an initial fragment $\alpha_1 \in \sigma(\tau)$ and continues by repeatedly substituting a fragment α_{k+1} for the leftmost non-terminal of the fragment $(((\alpha_1 \circ \alpha_2) \cdots) \circ \alpha_k)$. Bod defines the probability of substituting a fragment $\alpha = {}_A(\alpha_1 \cdots \alpha_k)$ for a non-terminal A, as the number of occurrences of α in the treebank, divided by the total number of occurrences of fragments with label A (Bod, 1993; Bod, 1995). Thus, $p(\alpha) = f(\alpha)/\sum_{\alpha' \in \sigma[\mathcal{C}_A]} f(\alpha')$. The probability of a derivation is defined as the product of the probabilities of the substitutions that it consists of; $p(\alpha_1 \circ \cdots \circ \alpha_m) = p(\alpha_1) \cdots p(\alpha_m)$. The probability of a constituent is equal to the probability that any of its distinct derivations is generated, i.e., the sum of the probabilities of all derivations of that constituent. Let τ be a constituent that is derived from the corpus by derivations $d_1, \ldots, d_n$, where each d_j consists of the fragments $\alpha_{1j} \circ \alpha_{2j} \circ \cdots \circ \alpha_{m_j j} = \tau$. Thus, α_{ij} denotes the i-th fragment of derivation j. Then the probability $P(\tau)$ of τ is given by

$$P(\tau) = \sum_{j=1}^{n} \prod_{i=1}^{m_j} p(\alpha_{ij}). \tag{1}$$

Problems with DOP The most important innovation that the data oriented approach has brought to stochastic parsing is the decision to use *all* fragments from the corpus directly as a stochastic tree substitution grammar. In this section we question the decision to define the probability of such a fragment as the relative frequency of the fragment among all fragments with the same root label. For a constituent $\tau = {}_A(\tau_1 \tau_2 \cdots \tau_k)$, the size of the set of initial fragments is given by the recursive equation $|\sigma(\tau)| = \prod_{i=1}^{k} (|\sigma(\tau_i)| + 1)$. The exponential nature of the fragment extraction operation, implies that large corpus trees make a disproportionately large contribution to the probability mass of the fragments. The biggest constituent of category A that exists in the data, determines the order of magnitude of the probability of all the fragments in that category.

We will illustrate this effect by a simple calculation. Suppose, for ease of calculation, that our treebank consists of balanced binary trees. Suppose furthermore, that one constituent τ_1 of category A has depth $h(\tau_1) = 6$, and that all n other constituents $\tau_2, \ldots, \tau_{n+1}$ of category A have depth $h(\tau_i) = 5$. For depth 5, the value of $|\sigma(\tau_i)|$ is equal to 458329, for depth 6, $|\sigma(\tau_1)| \approx 2.1 \cdot 10^{11}$. This means that the part of the probability mass of fragments of category A, that is absorbed by fragments with depth 6, is $(2.1 \cdot 10^{11} - 458329)/(2.1 \cdot 10^{11} + n \cdot 458329)$. For $n = 999$, i.e., 1 in 1000 constituents has depth 6, this means that 99.8% of the probability mass for category A, goes to fragments of depth 6.

Constraining the size and form of fragments Given the problem described above, how was DOP actually used with treebanks of non-trivial size? The answer lies in a simple heuristic: a set of constraints is imposed on the size and form of the fragments that are taken into consideration. Khalil Sima'an (Sima'an, 1999) suggested constraints on four different parameters: maximum depth, maximum number of substitution sites, maximum number of lexical items, and maximum number of consecutive lexical items. The right constraints compensate for the bias on fragment extraction. Only a very small percentage of large fragments complies with these constraints, while they do not particularly restrict the number of smaller fragments. Reasonable behavior on actual data was achieved with fragments having the following maximum values: two substitution-sites, three consecutive lexical items, nine lexical items in total, and depth four. Experiments showed that lower *and* higher values of the depth parameter caused a decrease in accuracy (Bonnema et al., 1997).

A New Probability Model We propose a new probability model for DOP, in which the probability of a fragment tree has a closer connection with the extent to which it is supported by occurrences in the treebank. The problem discussed in section show that the substitution probability of a fragment (relative to all fragments of the same category), is not proportional to the relative occurrence frequency of the fragment in the treebank. The classical DOP model thus employs a probability measure that invalidates the principle of prefering frequently occurring structures over alternatives that occur less frequent, and should therefore be abolished. Is it possible to maintain the basic ideas behind the data oriented parsing approach, while avoiding the disturbing property shown above?

Fragment Probability Let us reconsider the basic idea behind DOP. We think of every utterance as being generated by a stochastic process which combines fragments by means of the substitution operation. We do not have direct evidence about which fragments people actually use. But we can get indirect evidence about this, by (1) collecting a random sample from the population of utterances; and (2) registering a linguist's intuitions about the structure and interpretation of these utterances. These two processes result in what we call a treebank.

Such a treebank must be transformed into a hypothesis concerning the collection of substitutable fragments and their substitution probabilities. To collect corpus evidence for a single fragment, we should measure the number of times the fragment is *used* in the annotated corpus trees. This is achieved by viewing every corpus tree as the set of all its derivations, each consisting of a sequence of fragment substitutions. The evidence for a fragment supplied by a single constituent is then given by a combination of two factors: the relative frequency of the constituent, and the fraction of the possible derivations of this constituent that contain a substitution of the fragment. The latter measurement we will call the *fragment distribution* with respect to a particular constituent.

Given a fragment α and a constituent τ, we may define the fragment distribution $\phi(\alpha, \tau)$ as the fraction of all derivations of τ that *start with* α. Let $\delta(\tau)$ denote the set of all possible derivations of a constituent τ. Then,

$$\phi(\alpha, \tau) = \frac{|\{d_j \in \delta(\tau) : \alpha_{1j} \circ \cdots \circ \alpha_{d_j j} = \tau\}|}{|\delta(\tau)|} \tag{2}$$

with $\alpha_{1j} = \alpha$. Note that the elements of $\sigma(\tau)$ define a partition on the set $\delta(\tau)$, i.e. to each $\alpha \in \sigma(\tau)$ corresponds the subset $S \subseteq \delta(\tau)$ containing all derivations of τ that α starts. Hence we have $\sum_{\alpha \in \sigma(\tau)} \phi(\alpha, \tau) = 1$. For each constituent τ with the same category as the fragment α, we calculate the prior probability that the fragment α is used in a derivation of τ, multiplied by the probability that we select the constituent τ from the treebank. The probability of a fragment of category A expresses the joint probability of these two events. To compute the substitution probability of a fragment on the basis of the whole treebank, we take the sum of this product over the set of constituents of category A present in the treebank:

$$p'(\alpha) = \sum_{\tau \in \mathcal{C}_A} F(\tau) \phi(\alpha, \tau) \tag{3}$$

In any derivation of τ a non-root variable on τ is either internal to a fragment, or a substitution variable. Since any combination is allowed, the cardinality of $\delta(\tau)$ is equal to the cardinality of the powerset of the set of all non-root variables in τ. Hence, we have $|\delta(\tau)| = 2^{N(\tau)}$. The number of derivations of τ that start with α is given by substracting the available substitution variables of α from the available substitution variables of τ. If τ has $N(\tau)$ substitution variables for which to choose between substituting (for this variable) or not, and an initial fragment α is given,

then only $N(\tau) - N(\alpha)$ substitution nodes remain available. Substituting in (2) gives

$$\phi(\alpha, \tau) = \frac{2^{N(\tau)-N(\alpha)}}{2^{N(\tau)}} = \frac{2^{N(\tau)}2^{-N(\alpha)}}{2^{N(\tau)}} = 2^{-N(\alpha)} \tag{4}$$

We define $\phi(\alpha, \tau) = \phi(\alpha) = 2^{-N(\alpha)}$, if $\alpha \in \sigma(\tau)$, and let $\phi(\alpha, \tau) = 0$ for constituents τ such that $\alpha \notin \sigma(\tau)$. Equation (4) shows that the prior probability that a fragment α is used in a derivation of a constituent τ, is independent of τ, and depends on the complexity of α alone. This is an important property of the proposed probability model.

Lemma 1 *For every constituent tree τ,*

$$\sum_{\alpha \in \sigma(\tau)} 2^{-N(\alpha)} = 1. \tag{5}$$

A detailed proof of this lemma is given in an extended version of this text (Bonnema et al., 1999). Since $\phi(\alpha, \tau) = 0$ for constituents τ such that $\alpha \notin \sigma(\tau)$, we restrict the sum over $\mathcal{C}_A$ in equation (3) to constituents τ that are started by α, i.e. for which $\alpha \in \sigma(\tau)$ holds. If $\mathcal{C}_\alpha$ denotes the set of all constituents of $\mathcal{C}$ that are started by α, then $\sum_{\tau \in \mathcal{C}_\alpha} f(\tau) = f(\alpha)$ and therefore $\sum_{\tau \in \mathcal{C}_\alpha} F(\tau) = F(\alpha)$. Thus, taking the sum of the relative frequencies of all constituents that are started by the fragment α, amounts to taking the relative frequency of α itself.

Given a treebank $\mathcal{T}$ and the set $\mathcal{C}$ of constituents occurring in $\mathcal{T}$, we define the probability of a fragment α to be given by the probability function $p' : \sigma[\mathcal{C}] \rightarrow [0, 1]$, with

$$p'(\alpha) = 2^{-N(\alpha)} F(\alpha) \tag{6}$$

In the extended version (Bonnema et al., 1999) we use lemma 1 to prove the following theorem.

Theorem 1 *Let $\mathcal{C}$ be the set of constituents occurring in a corpus $\mathcal{T}$. Then,*

$$\sum_{\alpha \in \sigma[\mathcal{C}_A]} 2^{-N(\alpha)} F(\alpha) = 1 \tag{7}$$

Behavior of the New Probability Model We demonstrate how the new DOP model assigns probabilities to trees, and make a comparison with *probabilistic context free grammars* (PCFGs) (Booth and Thompson, 1973) and former DOP models. We demonstrate that the new model is identical to a PCFG model when the independence assumption, as made by all PCFG models, is validated by the data. Subsequently, we show with an example how the new model improves on a PCFG when the independence assumption is *not* validated. It will become apparent that the former DOP models did not improve upon PCFG models in this way.

The first example concerns a hypothetical treebank, in which the trees do not exhibit any dependencies between the PCFG rewrite rules that constitute them. The formal definition of such a treebank is given below.

Let G be a PCFG-grammar. With respect to a treebank $\mathcal{T} = \tau_1, \ldots, \tau_n$, the production probabilities of G are given by the standard relative frequency estimator (Chi and Geman, 1998):$\hat{p}(A \rightarrow \alpha) = f(A \rightarrow \alpha)/f(A)$. The probability that G assigns to a tree τ, is given by $p(\tau) = \prod_{(A \rightarrow \alpha) \in G} p(A \rightarrow \alpha)^{f(A \rightarrow \alpha; \tau)}$. Let $\mathcal{T}$ have the property that for all fragments β occurring in $\mathcal{T}$, the following holds.

$$\frac{f(\beta)}{f(r(\beta))} = \prod_{(A \rightarrow \alpha) \in G} p(A \rightarrow \alpha)^{f(A \rightarrow \alpha; \beta)} \tag{8}$$

	τ	$F(\tau)$	PCFG	new DOP	old DOP
(1)	$s(_A(0))$	1/8	1/8	1/8	1/12
(2)	$s(_A(1))$	1/8	1/8	1/8	1/12
(3)	$s(_B(0))$	1/8	1/8	1/8	1/12
(4)	$s(_B(1))$	1/8	1/8	1/8	1/12
(5)	$s(_A(0)_B(0))$	1/8	1/8	1/8	1/6
(6)	$s(_A(0)_B(1))$	1/8	1/8	1/8	1/6
(7)	$s(_A(1)_B(0))$	1/8	1/8	1/8	1/6
(8)	$s(_A(1)_B(1))$	1/8	1/8	1/8	1/6

Figure 1: Example trees, their relative frequencies and probabilities.

This equation expresses the proposition that the application of a rewrite rule of G in $\mathcal{T}$, is an independent event. Call this the *independence constraint.* Figure 1 shows a possible instantiation of $\mathcal{T}$, where G contains the rules $S \rightarrow A$ and $S \rightarrow B$ with probability 1/4, and $S \rightarrow AB$, $A \rightarrow 0$, $A \rightarrow 1$, $B \rightarrow 0$ and $B \rightarrow 1$ with probability 1/2.

Given the independence constraint, we can demand of a unbiased language model that the probabilities it assigns to trees occurring in the data, equals their observed relative frequency. By definition of $\mathcal{T}$, a PCFG employing the relative frequency estimator, will assign correct probabilities to all trees in $\mathcal{T}$. The new DOP model assigns correct probabilities to the trees as well. In fact, the new model is identical to a PCFG, under the independence constraint, for any choice of G (Bonnema et al., 1999). The former DOP model seems heavily biased towards the lager trees. In the next example we will see how the three models behave if we drop the independence constraint.

We construct a new corpus, by taking all instances of tree (2), and swapping their $_A(1)$ with the $_A(0)$ in all instances of tree (5). This causes tree (2) to become equal to tree (1), and tree (5) to tree (7). Our new corpus now consists of the 6 trees given in figure 2

Selection of the rule $_S(A)$ should now increase the probability of $_A(0)$ as a continuation of A. To the PCFG model the treebank is identical to the previous one, since the relative frequency of rule application did not change. The new DOP model, on the other hand, seems to accurately represent the dependencies in the trees. Take for example the four trees that have an identical relative frequency of 1/8: trees (2), (3), (5) and (6). Tree (5) has a clear internal dependency. The data show that $_S(AB)$ and $_A(0)$ exhibit a tendency to avoid each other. Tree (6) has the adverse dependency. We see this dependencies reflected in the probabilities assigned to trees (5) and (6), that are respectively 1/64 below and above the PCFG probabilities.

Constituents (2) and (3) exhibit no internal dependencies between rules. Their assigned probability is therefore equal to the probability assigned by the PCFG model, and falls exactly between the values assigned to (5) and (6). The probabilities of the former DOP model also show differences related to internal dependencies, but even greater differences related to difference in size.

Conclusion We have given a detailed demonstration of counterintuitive predictions which the "classical" DOP model generates. The impact that a piece of data has on the predictions of a data oriented parsing system seems to be primarily determined by the sizes of the trees that it occurs in, rather than by its overall

	τ	$F(\tau)$	PCFG	new DOP	old DOP
(1)	$s(_A(0))$	1/4	1/8	12/64	6/48
(2)	$s(_B(0))$	1/8	1/8	8/64	4/48
(3)	$s(_B(1))$	1/8	1/8	8/64	4/48
(4)	$s(_A(0)_B(1))$	1/4	1/8	11/64	11/48
(5)	$s(_A(1)_B(0))$	1/8	1/8	7/64	7/48
(6)	$s(_A(1)_B(1))$	1/8	1/8	9/64	9/48

Figure 2: Example trees, their relative frequencies and probabilities.

occurrence frequency. We proposed an alternative definition of fragment probability that does not suffer from such biases. The measure for the involvement of a fragment in the derivations of a lexicalized tree is shown to be a prior probability depending on the complexity of the fragment alone. This measure sums to unity over all possible fragments of a lexicalized tree. This result may be used to show that the proposed model defines an STSG with proper production probabilities. In an example, we demonstrated how the probability of parse trees, as assigned by the new model, compares with those assigned by probabilistic context free grammars and by "classical" DOP models.

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Consequences from Quine

Robin Clark (1), Natasha Kurtonina (2)

(1) Department of Linguistics, University of Pennsylvania

(2) Fitchburg College, Massachussetts

Quine (1960) gave a combinatory logic that was fully equivalent in expressive power to First Order Logic (FOL) but which eliminated syntactic variables. In this paper, we will reexamine Quine's logic, provide an exact semantics and proof theory for it, and show how this logic can be dynamicized without reference to syntactic variables. We aim, therefore, to give a full dynamic semantics, with an appropriate proof theory, based on Quine's combinatory logic. Moreover, we show that our reconstruction of Quine's combinatory logic is expressive enough to define the operators of Arrow Logic. We are particularly interested in analyzing the role played by syntactic variables in dynamic models of semantics. In general, dynamic models of semantics hang their dynamism on assignments of entities to syntactic variables; see, for example, Groenendijk, Stokhof & Veltman (1996) or van Benthem (1996) for discussion of variable assignments in dynamic models. The model we propose, below, eliminates syntactic variables in favor of combinators that directly bind semantic arguments. It is, therefore, of some general interest to show that such a system has a dynamic interpretation.

An interesting and important application of Quine's combinatory logic is reference tracking in natural language. Consider, for example, *switch reference* systems, as exemplified by Zuni (Stirling, 1993).

(1) An leonal-kwin pro_i te'ci-nan lelo-nan pro_i kwato-p
his box at arrive-SAME box-inside enter-DIFF
pro_j an-alt-u-nan pro_j iteh-k'aia-kae
indirective-be.closed-CAUSE-SAME throw-river-PAST

"He_i came-SAME to where the box was lying; he_i entered-DIFF the box and he_j closed-SAME it for him_i and he_j threw it into the river."

In the above, *-nan* marks that the subject of the following clause will be the same as the subject of the current clause and *-p* marks that the subject of the following clause will be different than the subject of the current clause. The switch markers behave in an inherently dynamic way. They inform the hearer that the reference of the next subject should either be maintained (in the case of *-nan*) or that the hearer must find a different discourse entity to fill in the subject position. We should note that switch reference is subject to a great deal of variation across languages. In particular, it is often the case that switch reference marks more than corefence or obviation; indeed, switch reference markers may

also encode temporal relations and even spatial relations. Furthermore, switch reference often occurs between a subordinate clause, which bears the switch reference morpheme, and the superordinate clause, which determines the tense of the embedded clause. Finally, languages may vary in the way they interpret switch reference and plurality. See, for extensive discussion, Stirling (1993).

We will show that Quine's combinatory logic (QCL) can be easily adapted to provide a *compositional* account of switch reference and similar reference tracking systems. Basically, Quine's logic works by semantically binding a single argument of a predicate using a combinator "Der." In order bind several positions in a complex predicate, Quine needed combinators to shift and identify arguments; he gave two inversion combinators ("Inv" and "inv")and a reflection combinator ("Ref") to do this. Finally, he gave two boolean combinators—Cartesian Multiplication ("×"), which corresponds to coordination, and negation ("Neg")—which make the system equivalent to FOL. These combinators combine with n-place predicates to form expressions in QCL. Quine gives the following definitions:

(2) a. *Derelativization:*
(Der $P)x_1 \ldots x_{n-1}$ if and only if there is something x_n such that $Px_1 \ldots x_n$;
b. *Major Inversion:*
(Inv $P)x_1 \ldots x_n$ if and only if $Px_nx_1 \ldots x_{n-1}$;
c. *Minor Inversion:*
(inv $P)x_1 \ldots x_n$ if and only if $Px_1 \ldots x_{n-2}x_nx_{n-1}$;
d. *Reflection:*
(Ref $P)x_1 \ldots x_{n-1}$ if and only if $Px_1 \ldots x_{n-1}x_{n-1}$;
e. *Negation:*
(Neg $P)x_1 \ldots x_n$ if and only if not $Px_1 \ldots x_n$;
f. *Cartesian Multiplication:*
$(P \times Q)x_1 \ldots x_n y_1 \ldots y_m$ if and only if $Px_1 \ldots x_n$ and $Qy_1 \ldots y_m$.

We will revise Quine's system by giving an explicit semantics and corresponding proof theory for it. We also prove that every closed first order formula has at least one corresponding combinatorial translation. For example, the first order sentence in (3)a translates into the expression in (3)b in QCL:

(3) a. $\exists x \exists y[Pxy \wedge Qxyx]$
b. (Der(Ref(Der(Ref(Inv(inv(Ref (Inv $(P \times Q)$)))))))))

A *dynamic* version of QCL requires that we introduce new combinators for memory management; in particular, this addition will allow us to model a switch reference system. In essence, we require a special memory location, call it a *pseudo-name*, into which we can store a discourse entity for future reference. We can define a special combinator, LOAD, which will store a discourse into the pseudo-name. We now define two combinators, SAME and DIFF, which we can use to manage the memory. In essence, SAME will maintain an entity already LOADed in the pseudo-name while DIFF will test the current proposition with the current value of the pseudo-name and the LOAD a new value into it.

We can think of SAME and DIFF as dynamic binding combinators which differ from Der in making reference to the value of the pseudo-name (our memory store), call it c_*. Consider, now, the following admittedly artificial example:

(4) A man$_1$ entered. A boy$_2$ saw him$_1$. He$_2$ ran away.

On this analysis, we add SAME and DIFF to Quine's inventory of combinators, discussed. LOAD is treated as a normal predicate. We can now model the sequence of sentences in (4) by the following (where SEEx, y is interpreted as "x sees y"):

(5) a. (SAME (Ref (Ref (× (× LOAD MAN) ENTER)))
b. (DIFF (Der (Ref (Inv (× BOY SEE)))))
c. (SAME RUN-AWAY)

The expressions in (5) can be interpreted as follows: First, in (5)a, a referent is loaded into c_* and it is asserted of the value of c_* that it is a man that entered. Furthermore, the value of c_* is preserved for the next clause. Second, in (5)b, it is asserted that there is a boy and that this boy saw whatever is the value of c_*. Notice that the inversion combinators must be used to make c_* the subject of a 1-place predicate. Finally, a new value is LOADed into c_* by the DIFF combinator. In (5)c it is asserted that the new value of c_* ran away.

An attractive feature of this system is that we can give a *proof theory* for it in a sequent calculus form. We will first give a sequent presentation for Quine's basic system, QCL, by defining left- and right-introduction rules for Quine's combinators. The next system will correspond to dynamicized QCL. Here, we have to take into account how memory management works in the deductive presentation. We use Labeled Deduction for presenting the sequent calculus. Sequents for dynamic combinators will be of the form: $\delta;\ X \Rightarrow Y$ where δ stands for "memory box" and X and Y are sequences of labeled formulas. The content of the memory box is managed by left- and right-introduction rules for SAME and DIFF.

An interesting property of CL is its versatility of expression. For example, we can easily formulate modal propositional operators that are analogous to Quine's combinators with the following truth conditions:

(6) Modal Combinatory Logic (MCL)

$$
\begin{array}{lll}
x_1 \ldots x_{n-1} \models Dp & \text{iff} & x_1 \ldots x_{n-1} x_n \models p \quad \text{for some } x_n \\
x_1 \ldots x_n \models Ip & \text{iff} & x_n x_1 \ldots x_{n-1} \models p \\
x_1 \ldots x_n \models ip & \text{iff} & x_1 \ldots x_{n-2} x_n x_{n-1} \models p \\
x_1 \ldots x_n \models Rp & \text{iff} & x_1 \ldots x_n x_n \models p \\
x_1 \ldots x_n y_1 \ldots y_m \models p \times q & \text{iff} & x_1 \ldots x_n \models p \text{ and } y_1 \ldots y_m \models q \\
x_1 \ldots x_n \models Np & \text{iff} & x_1 \ldots x_n \not\models p
\end{array}
$$

We claim, first, that Arrow logic (van Benthem, 1994; Venema, 1996) is definable within MCL and, second, that the operators of categorial grammar can also be defined. Let us turn, first to Arrow Logic. Most of the predicates of Arrow Logic are straightforward; sequential composition, however, merits some attention here. Sequential composition has the following truth conditions:

(7) $ab \models A \bullet B$ iff $\exists c(ac \models A \wedge cb \models B)$

We therefore need to establish the following:

(8) CLAIM. Sequential composition is definable in MCL.

First, we observe that the combinator I^- is definable.

$$x_1 \ldots x_n \models I^- p \quad \text{iff} \quad x_2 \ldots x_n x_1 \models p$$

Next we define $A \bullet_{\text{MCL}} B$ by $IDRI^-(A \times B)$. Notice that $\bullet_{\text{MCL}}$ has the same truth conditions as normal $\bullet$, as we show below:

(9)
$$
\begin{array}{ll}
ab \models IDRI^-(A \times B) & \text{iff} \\
ba \models DRI^-(A \times B) & \text{iff} \\
bac \models RI^-(A \times B) & \text{iff for some } c \\
bacc \models I^-(A \times B) & \text{iff for some } c \\
accb \models (A \times B) & \text{iff for some } c \\
ac \models A \text{ and } cb \models B &
\end{array}
$$

Now the operators of categorial grammar (which also have a dynamic interpretation in Arrow logic) can be defined in our framework by:

(10) a. $A\backslash B$ is equivalent to $N((IA) \bullet_{\text{MCL}} (NB))$.
b. B/A is equivalent to $N((NB) \bullet_{\text{MCL}} (IA))$.

The proof of the truth conditional equivalence is straightforward.

The full version of the paper will explore the connections between QCL and other dynamic frameworks as well as suggest a possible computational implementation; that is, we will propose a programming language for QCL.

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Reciprocal Interpretation with Functional Pronouns

Alexis Dimitriadis
University of Pennsylvania

Sentence (1) has a reading under which John thinks "I like Mary," and Mary thinks "I like John." Under this reading, the "dependent" pronoun *they* is most naturally represented as a bound variable, and is therefore semantically singular.[1] But this pronoun is also the antecedent of the reciprocal *each other;* it is well-known that reciprocals require a plural antecedent, so where does this one find the plural antecedent it requires?

(1) John and Mary think they like each other.

The standard way to account for the dependent reading (Heim et al. 1991a, and many others) is to have the reciprocal find its plural antecedent (its *range* argument) outside the embedded clause, by raising via QR or simply by being bound non-locally. Heim et al. (1991a) give sentence (1) the following analysis:

(2) [John and Mary$_1$ each$_2$] think [that they$_2$ like [e$_2$ other]$_3$]
= John thinks "I like Mary", and Mary thinks "I like John".

In this representation, the *each* part of the reciprocal has raised to adjoin to the matrix subject, where it functions as a distributive operator introducing universal quantification over the atomic parts of the matrix subject, the plural individual *John and Mary;* it also binds the pronoun *they*$_2$ and its own movement trace e_2. The representation in (2) translates into the following semantics:

(3) $(\forall x_2 \cdot{\sqsubset} \mathrm{J}{\oplus}\mathrm{M}_1)\,\mathrm{think}(x_2, \hat{}[(\forall x_3 \cdot{\sqsubset} X_1)\; x_2 \neq x_3 \Rightarrow \mathrm{like}(x_2, x_3)])$

Here the lower universal quantifier is contributed by the remnant part of the reciprocal (e_2 *other*), which is assumed to raise locally. (The symbol $\cdot{\sqsubset}$ stands for *proper-atomic-part-of).*

This solution works because the dependent pronoun ranges over the elements of the matrix subject. Indeed, since reciprocals are subject to Binding Principle A, it is necessary to stipulate that such "long-distance" reciprocals are only possible when the embedded subject is bound by the distributor of the matrix subject. For example, sentence (4) does not have a long-distance interpretation (or any other, since the embedded subject is singular).

(4) * Ann and Mary think that I like each other.

However, there are configurations that allow dependent reciprocal readings under conditions of non-identity between the matrix and embedded subjects. Heim et al. were aware of sentences like (5a), and accounted for them by assuming that the possessive pronoun raises out of the subject NP, to a position from where it can bind the embedded subject. But examples like (5b) and (c) have dependent readings that are just as good, and they are not so easily accounted for. In (b),

I would like to thank Tony Kroch, Maribel Romero, Robin Clark, Yael Sharvit and Uli Sauerland for their contributions to this work. The responsibility for remaining errors and shortcomings is all mine.

[1] I will refer to this reading, non-standardly, as the *dependent* reading, as opposed to the *independent* reading which says that John and Mary both think the same proposition, "We like each other." Heim, Lasnik, and May (1991a), among others, have shown that the dependent plural reading of reciprocal sentences is distinct from a cumulative (i.e., vague) construal. If the embedded pronoun was interpreted cumulatively, it should be equally easy, given the right context, to derive the following "crossed" reading of sentence (1):

(i) John thinks that Mary likes him, and Mary thinks that John likes her.

But this reading is unavailable, or at least much harder to get than the dependent reading. It can also be shown that sentences with dependent pronouns have truth conditions that are stronger than those of corresponding sentences with full NPs.

the pronoun *them* would have to raise out of a relative clause; in (c), a reciprocal that long-distance raises would give the reading "John thinks that his mother likes Mary, and Mary thinks that her mother likes John." This reading is impossible; the correct reading, in which John thinks that his mother likes Mary's *mother* and vice versa, cannot be generated by raising the reciprocal.[2]

(5) a. Their coaches think they will defeat each other.
b. The lawyers that represent them$_i$ say they$_i$ will sue each other.
c. John and Mary think their mothers like each other.

The problem with such examples is that the binder of the reciprocal determines the reciprocal's *range argument,* the set of entities that the object of the reciprocal clause may range over: The dependent reading of sentence (5c) is that John thinks his mother likes Mary's mother, but wide scope for the reciprocal would say that John's mother saw Mary, and vice versa (or worse, that *John* saw Mary). Such interpretations are never possible: reciprocals always range over the same elements their local antecedent ranges over, regardless of what *that* may be dependent on.

What is needed for these examples is some way for the object of the reciprocal predicate to range over the elements of the embedded, not the matrix, subject; in sentence (5c), that would be the set of mothers. But if the "long-distance" reading involves the translation of the embedded subject as a bound variable, there is no potential antecedent anywhere in (c) that translates to the set of mothers!

The account I propose has two parts: first, we need a way for the dependent pronoun in (5b) to be effectively bound by an NP that is inside a relative clause. This is accomplished by treating the pronoun *they* as a paycheck pronoun, in the fashion of Engdahl's (1986) functional adaptation of Cooper (1979). Accordingly, dependent pronouns are translated as expressions of the form $W(u)$, where W is a free variable of type <e, e> and u is a free variable over individuals. The pronoun in (5b) is then interpreted as a function meaning something like "their clients", and sentence (5b) can be treated in whatever way we handle sentence (5c).

Second, we need a way to generate the set of values that the "range argument" of the reciprocal should range over. I propose that the reciprocal predicate uses the function represented by the embedded subject to generate this set. The problem is that under the standard treatments of paycheck pronouns, including Engdahl's, the embedded subject is not a function but a complex expression of type <e>, consisting of the function plus its argument (a variable bound by the matrix distributor). The desired function could only be recovered from this subject via lambda abstraction; if the subject is instead passed to some other expression (e.g., to the reciprocal predicate) via Functional Application, there is no way for the subject to be converted back into a function.

In earlier work (Dimitriadis, forthcoming), I treated the function argument needed by the reciprocal as a free variable, constrained by binding theory to match the function in the embedded subject (more generally: in the local ancecedent of the reciprocal). But in the framework of Jacobson's (1999a, 1999b) Variable Free Semantics, all pronouns are represented as functions (of type <e,e>), not as variables over individuals. This means that the function corresponding to the embedded pronoun is accessible to the reciprocal predicate, and there are a number of ways to recover the range of the reciprocal from such a function. One possibility is to generate the range by applying the function to the matrix subject; for example, in (5b) the set of lawyers is mapped to the set of clients. Another is to posit, as

[2]Heim et al. do not actually predict that the erroneous reading is possible: it is ruled out by their requirement that the reciprocal be coindexed with a local A-binder. But this means that there is no way to derive the correct reading of (5c), either. If the A-binder requirement was somehow relaxed to allow for long-distance reciprocals in this case, the best their system could do is predict the non-existent reading, as discussed.

in (Dimitriadis, forthcoming), that reference functions are implicitly resricted; the range can then be recovered by means of a maximality operator.

1 The range of reciprocals

A correct translation of sentence (5b) should claim that each lawyer x says that x's client will sue the other clients, or the other lawyers' clients. Even with the paycheck analysis of the dependent pronoun, the framework of Heim et al. (1991a) cannot generate this reading. If, contrary to the restrictions in their system, we were to allow a long-distance reciprocal in this sentence, it might receive the following interpretation:

(6) $(\forall x_2 \cdot \Pi\, \mathbf{lawyers}_1)\, \mathrm{say}(x_2, \hat{}[(\forall x_3 \cdot \Pi\, X_1)\ W(x_2) \neq x_3 \Rightarrow \mathrm{sue}(W(x_2), x_3)])$

This says that each lawyer expects his/her client to sue the other *lawyers.* The correct translation can be generated if we stipulate that the range argument of the reciprocal, the free variable X, should be interpreted as the set of clients instead of being coindexed with $\mathbf{lawyers}_1$; but this implies that the range of the reciprocal could be any set, when in fact it is rigidly determined: it can only be the set of entities that the reciprocal's *contrast argument,* $W(x_2)$, ranges over.

This problem is not limited to the account of Heim et al.; its equivalent is also found in other scopal treatments of reciprocals, including those of Sternefeld (1998) and Schwarzschild (1996). Sternefeld, for example, captures the semantics of weak reciprocity via membership in the cumulation of the reciprocal predicate. (In contrast, the account of Heim et al. relies on direct quantification and encodes the semantics of strong reciprocity). In dependent reciprocal sentences the entire reciprocal raises to the matrix clause, so that the dependent reading of (5b) would be as follows:

(7) $(\exists X)(X = \mathbf{lawyers} \wedge <\mathrm{X}, \mathrm{X}> \in {}^{**}\lambda xy[x \neq y \wedge \mathrm{say}(x, \hat{}[\mathrm{sue}(W(x), y)])])$

This is the same meaning as given by the Heim et al. (1991a) analysis: it claims that each lawyer x said that his or her client, $W(x)$, will sue one or more of the other *lawyers,* y. The correct semantics would require replacing the the last occurrence of y with $W(y)$.

Thus the problem of finding the right range for the reciprocal is not specific to the analysis of Heim et al. (1991a), or to their particular assumptions about distributivity or type of reciprocal relation. The core of the issue seems to be that the range of the dependent reciprocal depends on its local antecedent, but the raising analysis cannot properly take its contribution into account.

The question, then, is how to translate long-distance reciprocals so that the reference function of the reciprocal predicate's subject plays a role in computing the range argument of the reciprocal. To do that it is necessary for the reciprocal to have direct access to the function represented by the dependent pronoun, something that can be done in a natural way in the framework of Jacobson's (1999a, 1999b) Variable Free Semantics.

2 Variable-free semantics

Jacobson's system translates pronouns as the identity function $\lambda x.x$, an expression of type $< e, e >$). To allow them to occur in the same syntactic positions as ordinary NPs, she introduces families of type-shifting operators g and z, which allow unsaturated functions to combine properly with other sentence elements. The operator g achieves the equivalent of function composition: an expression expecting an NP can be combined with a function from individuals to NPs instead, and the result is a function from individuals to the original type of the expression, b. The

operator z, applied to a transitive expression like *love,* replaces one of its arguments with a function bound by a higher argument.

Space does not permit a proper exposition of Jacobson's system, so simplified versions of g and z are included here without comment:

(8) a. $g_c(\lambda a.t(a)) = \lambda f \lambda c.[t(f(c))]$ (<a, b> → <ca, cb>)
b. $z_b(\lambda x \lambda y.p(x)(y)) = \lambda f \lambda y.p(f(y))(y)$ (<X, eY> → <eX, eY>)

With the aid of z, the functions corresponding to bound pronouns are eventually supplied with the correct antecedent as their argument. Discourse pronouns remain unbound; the sentences they occur in translate into functions from individuals to sentences. For example, sentence (9a) is translated as in (b).

(9) a. Mary loves him.
b. $\lambda x.\text{loves}(f(x))(\mathbf{m})$

The context then supplies a salient individual as the referent of *him.*

An added benefit of the variable-free approach is that lexical NPs containing a dependent pronoun are compositionally translated as functions, and can therefore be handled just like simple pronouns. (Recall that sentences like (5c), in which the dependent pronoun was embedded in an NP, cannot be handled by the standard treatment). The NP *their mothers* in (5c) is translated compositionally into the function $\lambda x.$*mother-of(x).

2.1 Paycheck pronouns

While ordinary pronouns are treated as the identity map on individuals, $\lambda x_e.x$, Jacobson translates paycheck pronouns as the identity map on functions of type <e,e>, $\lambda f.f$ (or $\lambda f \lambda x.f(x)$). This is simply the result of applying the g operator to the identity function on individuals, so all pronouns can be given the same underlying representation. The second sentence of (10) is is translated as $\lambda f.\text{hates}(f(b))(b)$. In this case, the context supplies the mother function as the argument f.

(10) John loves his mother. Bill hates *her.*

3 Reciprocals in the variable-free system

For concreteness, I will use as a starting point the treatment suggested in (Heim, Lasnik, and May, 1991b), in which the *each* part of the reciprocal does not raise; its role is taken over by a covert distributor that is freely inserted, as in simple distributive sentences. We can then replace their their distributor (an NP operator) with a VP-adjoined one, that provides the same universal quantification over individual elements of the subject:

(11) $D = \lambda P \lambda z.(\forall x \cdot \Pi\, z) P(x)$

The translation that Heim et al. give to the reciprocal can be written as in (12a). The quantifier ranges over the possible objects of the reciprocal predicate. (A higher universal quantifier is introduced by the distributor). For the variable-free version we rewrite the range argument, the free variable X_i, as an extra argument of the reciprocal. After some more adjustments to allow evaluation over non-atomic individuals, we obtain the version given in (12b):[3]

(12) a. $\lambda\zeta\lambda y.\forall x_k(x_k \cdot \Pi\, X_i \,\&\, x_k \neq y)\zeta'(y, x_k)$
b. $\lambda P \lambda R \lambda x.(\forall y \cdot \Pi\, R, y \wedge x = \mathbf{0}) P(y)(x)$

[3]The symbol "∧" is the meet operation on the semilattice of individuals, i.e., x and y must have no part in common.

The range argument in effect causes the reciprocal to be treated as if it contained a pronoun; at any stage it can be bound via the z operator, or remain unbound and be passed up with the help of g.

In an ordinary distributed sentence, the distributor is directly combined with the VP, and can then be applied to the subject:

(13) a. (John and Mary) + D(ran).
[$\lambda z.(\forall x \cdot \Pi\, z)$ran($x$)](John and Mary)

Because of the extra argument of a reciprocal predicate, it cannot combine directly with D; it combines with $z(D)$ instead, to give (14b):

(14) a. $z(D) = \lambda Q \lambda z.\, \forall x \leq z\; Q(z)(x)$
b. $z(D)$ + (like each other) = $\lambda z.\, (\forall x \leq z)\; (\forall y \cdot \Pi\, z,\; y \wedge x = \mathbf{0})$ like(y)(x)

This is simply the Heim et al. account translated into variable-free semantics, but with VP-adjoined distributors. Because the subject is not buried in the subject-distributor complex as as it would be if the distributor was NP-adjoined, the range argument can be recovered from the distributor, as shown, instead of being left as a free variable. But this account is as incapable of handling dependent paycheck pronouns as the original; if the reciprocal predicate (14b) is not combined with a distributor, but is instead combined with a dependent paycheck pronoun, we get:

(15) a. The lawyers who represent John and Mary say they like each other.
b. they = $\lambda f \lambda w.f(w))$
c. like each other = $\lambda R \lambda x.(\forall y \cdot \Pi\, R, y \wedge x = \mathbf{0})$ like(y)(x)
d. g(l(they)) + g(like each other) =
$\lambda R \lambda f \lambda w.(\forall y \cdot \Pi\, R, y \wedge f(w) = \mathbf{0})$ like(y)($f(w)$)

(The pronoun type-lifts to $\lambda P \lambda f \lambda w.P(f(w))$, via l, then undergoes g in order to pass up the argument λR of the predicate). It can be seen that the paycheck function f is only applied to the subject of the reciprocal predicate; when the entire sentence is translated, the range argument R will be identified with the denotation of the matrix subject, which gives us the non-existent reading of clients liking lawyers.

3.1 Using the domain

What kind of adjustments can be made to give the correct semantics? If the translation of the reciprocal can expect to be combined with a functional subject, then we can dispense with the range argument and use the domain or range of the antecedent function in its place, translating the reciprocal as in (16a) or (b):

(16) a. $\lambda P \lambda r \lambda x.(\forall y \cdot \Pi\, \text{Dom}(r), r(y) \wedge r(x) = \mathbf{0})$ P($r(y)$)($r(x)$)
b. $\lambda P \lambda r \lambda x.(\forall y \cdot \Pi\, \text{Range}(r), y \wedge r(x) = \mathbf{0})$ P(y)($r(x)$)

For this to work, it is of course necessary that the pronoun functions come with domains, and that their domain be no larger than required by the pronoun's binder, i.e., the domain of a dependent pronoun should be co-extensive with the matrix subject. To keep things simple, I will write the domain as an open variable in the translation of the pronoun as in (17); it should actually be treated, in the variable-free spirit, as a second argument to the pronoun function. The domain of and range of a restricted function r are retrieved by application of the maximality operator; e.g., the domain is $\sigma x(\exists y\; r(x) = y)$. The restricted client function is:

(17) $r = \lambda x.\iota z(x \leq A \,\&\, \text{client-of}(z)(x))$

Given either of the translations in (16), we can capture the correct semantics for dependent reciprocals with or without paycheck pronouns.

The problem with the analysis as given is that it expects to find a function immediately above the reciprocal predicate. Although it is possible to arrange for the

distributor to pass the identity function to the reciprocal, this step seems unmotivated and artificial. Given the translation we are after, there seems to be no way around this: if we start with an expression that expects a subject of type <e> and then type-shift to bind the pronoun, we end up with plain bound-pronoun semantics, and there is no way to compute the correct range argument. If we assume a function argument, we need to go through the unnatural step of introducing a reference function between a simple reciprocal predicate and its distributive antecedent.

3.2 Mapping the range argument

A second, perhaps less ad hoc solution is as follows: Start with the reciprocal translation given in (12b), combine it with a verb, then apply the g operator twice to change both arguments into functional expressions, as in (18a). If we can manage to use the antecedent's reference function r for *both* f and g, we get the correct semantics shown in (b).[4] For example, in the translation of sentence (5c) the variable y will range over mothers, not over the set R, which will consist of John and Mary.

(18) a. like each other:
$\lambda g \lambda R \lambda f \lambda x.(\forall y \cdot \Pi\, g(R), y \wedge f(x) = \mathbf{0}) like(y)(f(x))$
b. they + like each other:
$\lambda R \lambda x.(\forall y \cdot \Pi\, r(R), y \wedge r(x) = \mathbf{0}) like(y)(r(x))$

Jacobson's framework does not seem to provide an operation that can do this, but this seems like a good place to introduce an extension. Note that this solution does *not* rely on function domains, and (leaving aside the magic step from (18a) to (b)) uses a single translation for the reciprocal.

Conclusion

Jacobson's Variable-Free Semantics makes it possible to handle, in a constrained way, dependent reciprocal sentences in which the embedded subject ranges over different values than its binder. Although I based my discussion on the Heim et al. model, the proposed solution is applicable to other, more articulated treatments of reciprocals.

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[4] If the local antecedent is a paycheck pronoun, then r is actually a variable over functions, and expression (18b) should be amended to pass up the argument λr. If r is the identity function or an NP containing the dependent pronoun, (18b) is correct as written.

The Semantics of Transitivity Alternations[1]

Edit Doron, The Hebrew University of Jerusalem

In theoretical linguistics, causative and middle verbs are usually derived by independent operations. But cross-linguistically, both mark the same transitivity alternations. This paper proposes a unified syntactic system for the derivation of both types of verbs, which, moreover, sheds new light on problems in the interface of semantics and morphology. One problem is the impossibility, mostly ignored in linguistic theory, of deriving the semantics of middle verbs from that of the corresponding transitive verbs. The second is explaining the identity found cross- linguistically between middle and reflexive morphology. The third is providing an alternative to the "event-decomposition" account of derived causative verbs.

The paper develops a non-lexicalist unified analysis of the semantics of causative and middle morphology. Both causative and middle verbs are derived from *roots*. In the Semitic languages, this derivation is morphologically marked by different templates. These templates denote *voice* (of which *middle* is one possible value) and *agency*, the thematic role of the verb's external argument (of which *causative* is one possible value). According to the present analysis, this form-meaning correspondence is mediated by syntax, which allows the parallel compositional construction of the form and the meaning of a verb from the forms and the meanings of its root and template.

I take a root R to denote either a property of events λe[R(e)] or a relation between individuals and events, e.g. λxλe[R(e,x)]. The root and its arguments are optionally embedded under a *light verb v* (Hale and Keyser 1993, Kratzer 1994) which relates an event to its Agent (more precisely Proto-Agent in the sense of Dowty 1991): λyλe[Agent(e,y)]. Whether or not a root is embedded under *v* is a syntactic property of the root. But this is only the unmarked case (morphologically encoded by the *simple* template). Two dimensions of markedness are introduced into a derivation by two additional types of syntactic heads: (a) *agency-heads* and (b) *voice-heads*.

(One) *Agency-heads* modify agency: The agency-head γ relates an eventuality to its cause: γ= λyλe[Cause(e,y)], and is morphologically realized as the *causative* template. Another agency-head, ι, classifies the eventuality as an action: ι = λe[Action(e)], and is morphologically realized as the *intensive* template.

(Two) *Voice-heads* modify voice: The voice-head μ (realized as the *middle* template) replaces the light head *v* in the derivation, which precludes the insertion of an additional Agent argument and results in the derivation of an intransitive verb. Another voice-head, the passive voice-head π (which is not discussed in the present paper), is morphologically realized as the *passive* template.

The present analysis of causative verbs in terms of a causative template is not equivalent to an analysis in terms of an additional causative predicate. A causative template is restricted to denote a particular thematic relation, which is not the same as introducing a predicate in general. For example, if a causative verb involves a single predicate, we expect it to denote an event, rather than a relation between events. The present analysis views a causative verb as denoting an event which has a causer participant. The paper reviews and rejects the purported evidence found in the literature (Parsons 1990, Pustejovsky 1995) for the analysis of causation in terms of event decomposition (based on the scope of temporal adverbials). Instead, I view the causal origin of an event as part of its characterization. Another type of event characterization is action (marked morphologically in Semitic by the intensive template). Clearly, event decomposition would not be appropriate for this latter type of characterization. Rather,

[1] I am grateful to the faculty and students of the Linguistics Department at the University of California at Santa Cruz where this research was conducted, and in particular to Daniel Büring, Giulia Centineo, Donka Farkas, Jorge Hankamer, Bill Ladusaw and Jim McCloskey.

cause and action are thematic concepts which characterize an event. Philosophically, both of these concepts are central, and none is reducible to the other (Davidson 1971).

The decomposition approach to causativity has additional drawbacks as an account for transitivity alternation. Under this view, the transitive verb is derived from the intransitive verb by means of the operator CAUSE. Since the transitive verb is derived, we expect a more highly marked morphology for it, yet sometimes it is the other verb which is morphologically marked, by the middle morpheme. Second, under the decomposition approach, the identity of the middle morpheme with the reflexive morpheme is completely unexpected. The reflexive morpheme presumably denotes the reflexive operator λPλx[P(x,x)], which applies to transitive verbs irrespective of CAUSE.

Chierchia 1989 goes in the opposite direction from that of event decomposition. He takes the transitive verb as basic, and derives the middle verb from it. This approach overcomes the shortcomings of the decomposition approach, but it runs into the converse of the first problem: even in languages with middle morphology, it is not necessarily the case that the transitive verb is unmarked; often, it is the transitive verb which is marked (as causative). Moreover, this direction of derivation faces a serious semantic problem. The problem is that there is no way to "eliminate" the semantic contribution of the transitive verb's external argument. This problem is usually ignored in the literature, but not by Chierchia, who is well aware of it, and nevertheless wants to derive the meaning of the middle verb from that of the transitive verb. His proposal is to analyze middle verbs as reflexive. Though this reduction of the middle voice to reflexivity accounts for the observation that reflexives are often derived by middle morphology, it is not independently motivated. Levin and Rappaport Hovav 1995 propose to maintain Chierchia's transitive-to-middle direction of derivation only for a subset of verbs, those which denote what they call "externally caused" events, and they reverse the direction of derivation for verbs which denote what they call "internally caused" events. But this distinction is ad-hoc, and moreover fails to account for pairs where both transitivity alternants are morphologically marked.

In sum, neither direction of derivation is tenable which operates on the causative and middle verbs themselves. Neither is derived from the other, but at the same time, neither is underived, which explains why there exist examples of the transitivity alternation where both verbs are morphologically complex. I claim that both causative and middle verbs are derived from a basic predicate, the root. A transitive verb is derived by combining the root with a morpheme which contributes an additional argument. In the unmarked case, this argument is an agent. A morpheme which specifically contributes a cause marks the derived verb with causative morphology. A middle verb is derived by combining the root with a morpheme which precludes the agent. All these different derivations from a single root are marked in the Semitic languages by a unified system of templates.

All verbs, nouns and adjectives in the Semitic languages are derived from (tri-)consonantal roots by intercalation with different *templates*, which are morphemes that consist of CV skeleta, vowel sequences and affixes. The root is usually the only common element shared by derivationally related forms. What is striking about the Semitic system is that while there are scores of templates which derive nouns from roots, the verbal system is extremely limited. Though the verbal system is on principle the same in all the Semitic languages, the actual forms vary from language to language. The present study is based on the forms found in Hebrew. Setting aside voice variation for the moment, each active verb in Hebrew is derived by one of exactly *three* templates. These templates, also found in Akkadian, Syriac, Arabic, are traditionally known as (a) the **simple** template, (b) the **intensive** template, and (c) the **causative** template. Since each and every active verb in Hebrew is derived by one of exactly three templates, it is natural to suspect that the choice of template is not arbitrary, but that it indicates some factor of the meaning of the derived verb. This indeed is the traditional view concerning the templates, as is suggested, for example, by the term **causative**. Modern linguists, on the other hand, have noted numerous examples where the semantic contribution of the template is unpredictable, and have concluded that these examples doom to failure any attempt at a

systematic analysis. Yet the semantics of the templates is totally systematic if one looks only at roots which derive more than a single verb, i.e. which derive contrastive pairs or triplets of verbs. The roots in (1), for example, all derive intransitive simple verbs, and also intensive and causative verbs. I point to the fact that for each such root in the language, the causative verb is transitive, i.e. induces an increase in valence by adding a *Cause* argument, whereas the intensive verb is intransitive, i.e. does not involve a change of valence, but only reclassifies the described event as an *Action*. Accordingly, the subject of an intensive verb must be animate, whereas simple and causative verbs are equally good with animate and inanimate subjects, as shown in (2):

(1) *root*	*simple verb (intransitive)*		*intensive verb (intransitive)*		*causative verb (transitive)*	
[q][p][c]	[q]a[f]a[c]	*jump*	[q]i[p]e[c]	*jump up&down*	hi[q][p]i[c]	*make jump*
[r][q][d]	[r]a[q]a[d]	*dance*	[r]i[q]e[d]	*actively dance*	hi[r][q]i[d]	*make dance*
[‘][p]	[‘]a[f]	*fly*	[‘]o[f]e[f]	*actively fly*	he[‘][]i[f]	*fly*
[h][l][k]	[h]a[l]a[x]	*walk*	[h]i[l]e[x]	*actively walk*	ho[][l]i[x]	*make walk*
[x][z][r]	[x]a[z]a[r]	*return*	[x]i[z]e[r]	*court*	he[x][z]i[r]	*return*
[p][q][d]	[p]a[q]a[d]	*command*	[p]i[q]e[d]	*be in command*	hi[f][q]i[d]	*put in charge*

(2)a ha-yeladim/ ha-mexirim qafcu
the children/ the prices jumped -SIMPL
'The children jumped.' 'The prices raised.'

b ha-yeladim/ * ha-mexirim qipcu
the children/ the prices jumped -INTNS
'The children/*the prices jumped up and down.'

The distinction in (2b) is expressible in English by using the main verb *do*, which, unlike the auxiliary *do*, only has an action meaning (as noted by Ross 1972):

(3)a The girls jumped up and down after the boys did it.
b * The prices jumped up and down after the taxes did it.

In the examples above, the simple verb is unergative. But if the simple verb is unaccusative, as in (4) below, then the corresponding intensive verb involves valence increase, in addition to the reclassification of the event as an action. The intensive verbs in (4) are therefore just as transitive as the equi-rooted causative verbs:

(4) *root*	*simple verb (unaccusative)*		*intensive verb (transitive)*		*causative verb (transitive)*	
[p][n][y]	[p]a[n]a[]	*turn*	[p]i[n]a[]	*turn out*	hi[f][n]a[]	*turn*
[g][d][l]	[g]a[d]a[l]	*grow*	[g]i[d]e[l]	*grow*	hi[g][d]i[l]	*increase*
[p][x][t]	[p]a[x]a[t]	*reduce*	[p]i[x]e[t]	*devaluate*	hi[f][x]i[t]	*reduce*
[t][b][‘]	[t]a[v]a[‘]	*drown*	[t]i[b]ea[‘]	*drown*	hi[t][b]ia[‘]	*drown*
[y][c][‘]	[y]a[c]a[]	*come out*	[y]i[c]e[]	*export*	ho[][c]i[]	*take out*
[t][‘][m]	[t]a[‘]a[m]	*match*	[t]e[‘]e[m]	*coordinate*	hi[t][‘]i[m]	*match*
[b][ö][l]	[b]a[ö]a[l]	*ripen*	[b]i[ö]e[l]	*cook*	hi[v][ö]i[l]	*ripen*

Again, intensive verbs indeed denotes actions. An intensive verb in (4) can only be predicated of an animate subject. The causative verb, on the other hand, may be predicated of any kind of cause (including abstract causes):

(5)a ba'alat-ha-bayit/ ha-avtala hifneta et-ha-dayarim
the landlady /unemployment turned-CAUS ACC the tenants
le-liökat-ha-avoda
to the employment agency

b ba'alat-ha-bayit pinta et-ha-dayarim
the landlady turned-out-INTNS ACC the tenants

c * ha-avtala pinta et-ha-dayarim
unemployment turned-out-INTNS ACC the tenants

Given a system of templates, there is no need to assume that the lexicon consists of morphemes as fine grained as verbs. Rather, the lexicon consists of coarser grained *roots*, whereas verbs are constructed from the roots by merging them with the *light verb* v and with *agency-heads*, ι and γ, which, first, determine whether the derived verb is a verb of action, a verb of causation or unclassified for these dimensions, and which, second, introduce an external argument. By principles of distributed morphology (Halle and Marantz 1993), the syntactic output is supplied a Vocabulary form by the morphological component of the grammar. Under the simplest conceivable form-meaning correspondence, every root R fused with ι should always be realized as an intensive verb, a root fused with γ should always be realized as a causative verb, and a root in isolation (in a verbal environment) should always be realized as a simple verb. Yet this is true only in the default case. The default features of the templates are [+ι] for INTNS, [+γ] for CAUS, and [-ι-γ] for SIMPL. Crucially, non-contrastive features are redundant, and therefore not marked, which clarifies why it is that verbs which are the unique derivational output from the root, i.e. verbs which are not part of a contrastive pair, tend to be idiosyncratic.

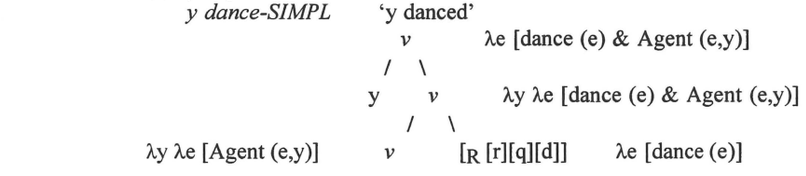
v denotes the thematic role Agent: λyλe[Agent(e,y)]. The licensing of v is a syntactic property of the root. In addition, the agency head ι also licenses v, but γ does not. ι classifies events as Actions: λe[Action(e)], whereas γ denotes the thematic role Cause: λyλe[Cause(e,y)]. The Cause thematic role is never identified with the thematic role of Agent, since causative morphology signals a marked Cause, i.e. a Cause which is not an Agent, whereas unmarked Causes are realized by default as Agents.

Functional heads combine with their complements not by function application, but by the rule of "identification" (Higginbotham 1985). For example, identification applies in (7) in the subtree where v and R are combined, in the way shown in (6), where s is the type of situations:

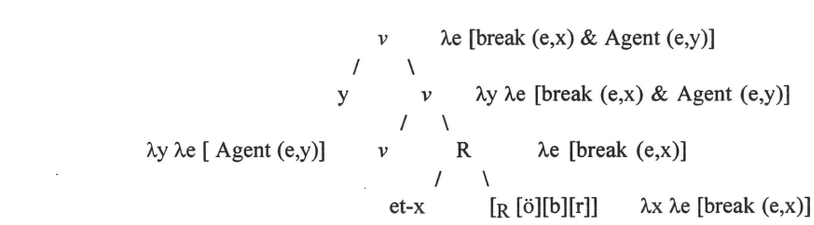
(6) ident $(\alpha_{<e,<s,t>>}, \beta_{<s,t>}) = \lambda P\, \lambda y_e\, \lambda e_s\, [\alpha(e,y) \,\&\, P(e)]\, (\beta)$

The other subtrees in (7) combine by function application. In addition, I assume that the event argument is bound by a tense operator higher in the tree, and I use *x, y, z* ambiguously for both variables and names. The roots in (7) and (8) are roots that license v, whereas the root in (9) does not:

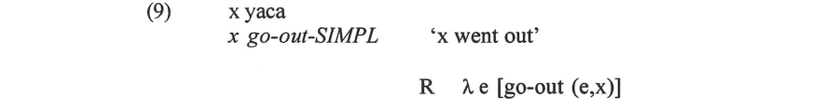
(7) y raqad
y dance-SIMPL 'y danced'

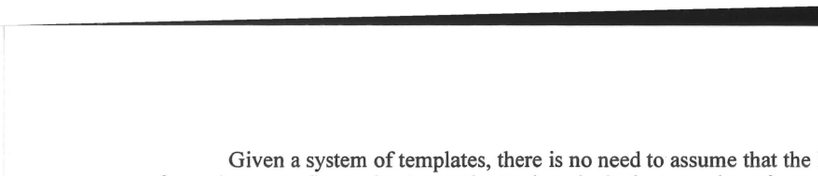


(8) y öavar et x
y break-SIMPL *ACC-x* 'y broke x'



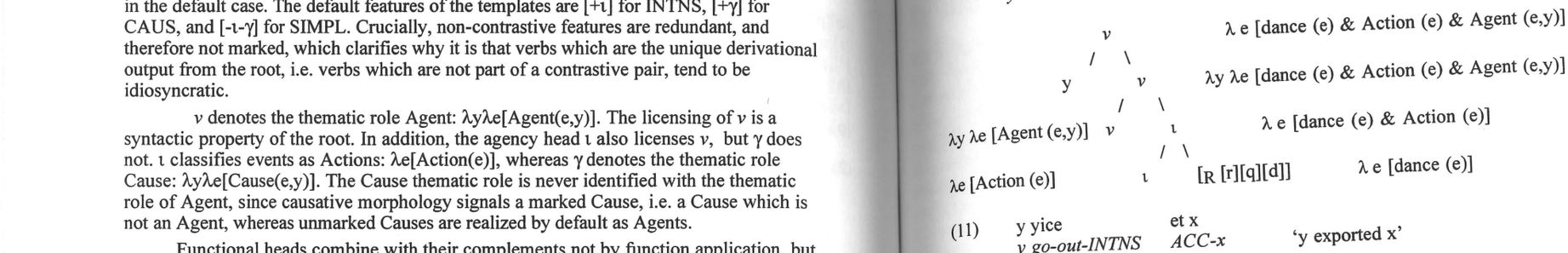
(9) x yaca
x go-out-SIMPL 'x went out'



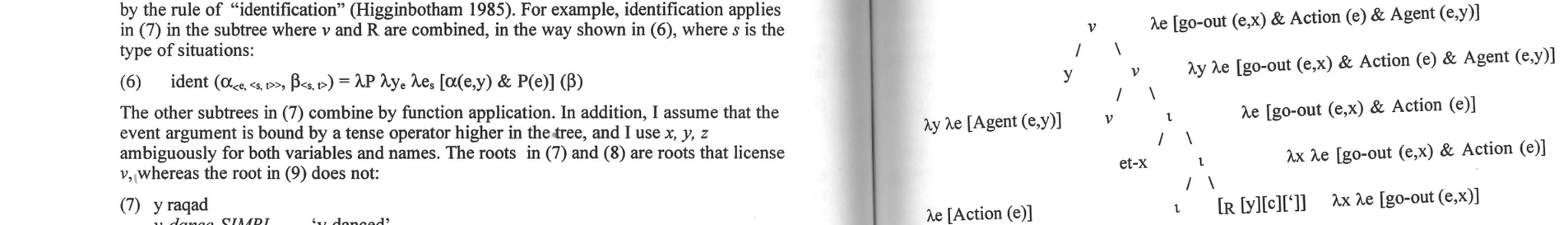


ι licenses v, whether or not the root does. From the familiar requirement that the Agent role is assigned at most once per event, the Agent of (7), for example, is the same as the Agent of the corresponding intensive verb in (10) (the same is true of (8) as well). But in (9), the root does not license v, therefore the Agent of the corresponding intensive verb in (11) is an additional argument, since v in this case is licensed by ι only:

(10) y riqed
y dance-INTNS 'y actively danced'



(11) y yice et x
y go-out-INTNS *ACC-x* 'y exported x'

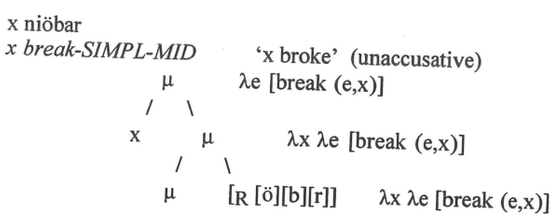


Unlike (10), in (12) there is an additional argument, γ's argument, which, as explained above, is different from the Agent:

(12) z hirqid et y
z dance-CAUS *ACC-y* 'z made y dance'
λz λe [dance (e) & Agent(e,y) & Cause (e,z)]

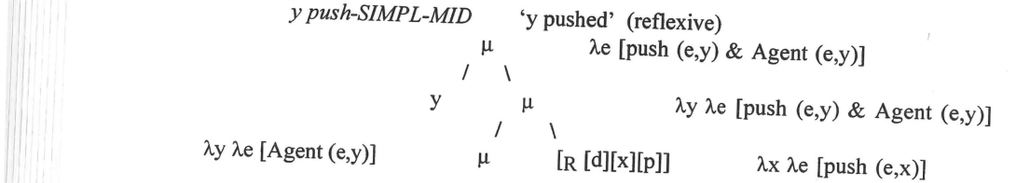
As is also true cross-linguistically, some middle verbs are unaccusative and others are reflexive.The middle template is the realization of a voice-head μ which modifies the root by voiding its licensing of v. This precludes the insertion of an additional Agent argument and results in the derivation of an unaccusative verb:

(13) x niöbar
x break-SIMPL-MID 'x broke' (unaccusative)



The reflexive reading of a middle verb results from the fact that, for some roots, μ itself relates the event to one of the root's own arguments by the Agent relation. In (14), since μ is a modifier, its argument is identified with the root's:

(14) y nidxaf
y push-SIMPL-MID 'y pushed' (reflexive)



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Deriving and resolving ambiguities in *wieder*-sentences*

Markus Egg, Universität des Saarlandes

Abstract

The frameworks of underspecification and of optimality theory can interact in the treatment of semantic ambiguity. Underspecification allows a compact yet comprehensive representation of an ambiguous expression, which is at the same time a suitable input for an optimality theory based resolution component that determines the preferred reading of the expression. Ambiguities of sentences with *wieder* 'again' are investigated to explore this claim.

1 Introduction

The framework of underspecification allows the *derivation* of simple, and at the same time cognitively adequate representations of natural language ambiguities. In contrast, optimality theory, if applied to semantically ambiguous expressions, may be used for the context-dependent *resolution* of these ambiguities. Following Blutner and Jäger (1999), this paper explores the possibilities of combining both frameworks in the treatment of a classic case of ambiguity, viz., the ambiguity that arises from the interaction of *wieder* 'again' with complex verbs. The goal is an adequate division of labour between semantic construction and optimality theoretical interpretation constraints, which uses underspecification to derive semantic representations that are compact yet comprehensive, and at the same time a suitable input for an optimality theory based resolution component that determines the preferred reading of the expression with respect to a given context.

(1) is a simple example for the relevant ambiguity. It has two readings which differ in their presuppositions. In the so-called 'repetitive' reading, Max must have opened all windows before, whereas the 'restitutive' reading only presupposes that all windows were open before.

(1) daß Max alle Fenster wieder aufmachte
that Max all windows again opened
'that Max opened all windows again'

Word order influences the semantics of *wieder*-sentences. E.g., it is often claimed that switching the object NP and *again* in (1) rules out the restitutive reading:

(2) daß Max wieder alle Fenster aufmachte

The focus is on cases like (1) and (2), where *wieder* modifies *telic* verb(al projection)s, i.e., those that introduce a stative property for the aftermath of eventualities in their extension ('eventuality' refers to all kinds of states of affairs). Here the presupposition of the restitutive reading is this 'aftermath property'. E.g., for *Max open- the window* this property is *the window be- open.*[1] For other cases of *wieder*-modification see in particular Fabricius-Hansen (1983).

The paper is structured as follows: after some discussion of previous approaches to the repetitive/restitutive (RR) ambiguity, the frameworks relevant for the analysis (underspecification and optimality theory [OT]) are sketched briefly. Then an underspecified analysis of the RR-ambiguity, and its resolution by OT constraints is presented.

2 Previous approaches

The intuition of Generative Semantics was to model the RR-ambiguity in terms of scope variation of a semantically invariable *wieder*. Researchers like Dowty (1979) and v. Stechow (1996) rephrased this intuition in semantic and syntactic terms, respectively.

These approaches presuppose a decomposition analysis of complex verbs like *open*. They are analyzed in terms of operators like CHANGE and BECOME, which introduce a causation and a

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[1] Issues of sentence mood and tense are neglected here. Sentences minus mood and tense (called 'sentence radicals') are interpreted as properties of eventualities and written with an uninflected main verb.

change of state, respectively. The argument of BECOME denotes the aftermath property of the verb. E.g., Dowty represents *open* as $\lambda x \exists P.P(x)$CAUSE BECOME($\mathbf{open}'(y)$) (simplified here), where $P(x)$ introduces the cause of the causation, some activity of the subject of *open*.

The RR-ambiguity then follows from the scope positions of *wieder*, above the whole verb for the repetitive reading, and below BECOME, for the restitutive reading. This raises the question of how to insert the meaning of *wieder* within the semantics of the complex verb.

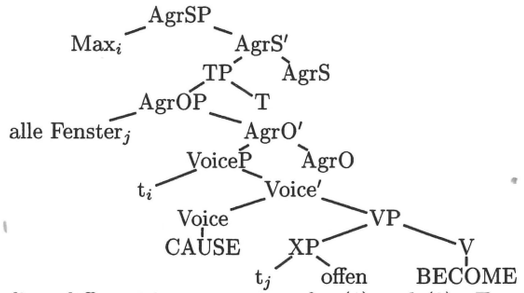
To this end, Dowty postulates equivalence between the repetitive readings of *wieder*-sentences (on the left of (3)) and their restitutive readings (on the right). The postulate is strongly simplified:

(3) $\forall p \forall q.\Box[\mathbf{again}'(p \text{ CAUSE BECOME}(q)) \leftrightarrow p \text{ CAUSE BECOME}(\mathbf{again}'(q))]$

However, this meaning postulate is problematic in that it allows one to infer the repetitive reading from the (weaker) restitutive reading. This problematic inference is eventually responsible for the unwanted side effects which Zimmermann (1993) notes for this postulate.

v.Stechow assumes a *syntactic* decomposition of complex verbs like *open*. The relevant part of the syntactic structure of (1) and (2) (without *wieder*) is depicted in (4), where the verb is introduced not in a single leaf node but in the VoiceP as a whole. The adjective *offen* 'open' denotes the property that holds for the second argument of the verb in the aftermath of *aufmachen*-eventualities. In (4) there are different *adjunction positions* for an adverbial like *wieder*. Since its syntactic position determines its semantic scope, this leaves room for structural ambiguity: if *wieder* is adjoined to VoiceP or a higher phrase, the whole verb is in its scope, if adjoined to XP, it is in the scope of BECOME.

(4)



This predicts different interpretations for (1) and (2). To receive case, NPs must be moved from their positions within VoiceP (as indicated by the traces t_i and t_j) into the specifier position of their respective agreement phrase (AgrS and AgrO) on the surface structure. Consequently, the deep structure position of *wieder* (and hence its scope relation to CAUSE/BECOME) cannot be uniquely reconstructed when it appears next to the verb on the surface like in (1) (it might be adjoined to XP or VoiceP). This implies the RR-ambiguity of (1). In contrast, if the object NP is next to the verb on the surface like in (2), the adverb must be adjoined to AgrOP or higher, hence, it outscopes CAUSE/BECOME, only the repetitive reading should be possible.

However, Blutner and Jäger (1999) point out a restitutive reading for (2), which runs counter to the predictions of the approach. This reading can be glossed as 'all windows had been open *simultanously* before, and Max restituted this state of affairs'. I.e., CAUSE has widest, and the quantifier, narrowest scope, with *wieder* having intermediate scope.

Blutner and Jäger (1999) assume ambiguity and invariant scope position of *wieder*. They analyze its semantics as (5). The material to the right of the oblique expresses the presupposition:

(5) $\lambda P \lambda i.P(i)/\exists j.j < i \wedge f(P)(j)$

In prose: semantically, *wieder* is the identity mapping for properties of eventualities P and presupposes a preceding eventuality in the extension of $f(P)$. f is an open parameter, which can be instantiated as either identity mapping or a function RES from (telic) properties of eventualities P onto the stative aftermath property involved in P as laid out in section 1.

Disregarding questions of word order for the moment, this predicts a fourfold ambiguity for the semantics of (1) and (2). There are two scoping possibilities of *wieder* and the object NP (which determine whether the universal quantifier appears in the presupposition or not), each of which allows two instantiations of the function f:

(6) $\lambda i \forall x.\mathbf{window}(x) \rightarrow \mathbf{open}'(\mathbf{m},x)(i)/\exists j.j < i \wedge f(\lambda i.\mathbf{open}'(\mathbf{m},x)(i))(j)$

(7) $\lambda i \forall x.\mathbf{window}(x) \rightarrow \mathbf{open}'(\mathbf{m},x)(i)/\exists j.j < i \wedge f(\lambda i.\forall x.\mathbf{window}(x) \rightarrow \mathbf{open}'(\mathbf{m},x)(i))(j)$

(6) covers two readings. If f is identity, the presupposition is that Max has opened every window before, if f is RES, that every window was open before. From (7), if f is identity we get the reading with the presupposition that there was a previous eventuality of Max's opening every window. In (7), f can also be instantiated as RES. But it is unclear what RES($\lambda j \forall x.\mathbf{window}(x) \rightarrow \mathbf{open}'(\mathbf{m},x)(j)$) means: if Max is opening every window, it may well be that someone else closes the windows after him, so that the result of Max's opening every window need not be that every window is open *simultaneously*. But to derive the restitutive reading for (2), the above application of RES would have to have this result. Even if we grant this point, another problem arises: Blutner and Jäger predict that $\forall$ has scope over CAUSE in every reading of (1) or (2), but in the restitutive reading for (2) this scope relation is reversed. Hence, they cannot derive this reading of (2).[2]

In sum, the discussion of previous approaches to the RR-ambiguity has shown that the derivation of the semantic representations that represent the possibilities of scope interaction between *wieder*, complex verbs, and quantifiers still is a problematic issue.

3 The background of the analysis

The proposed approach is founded on two frameworks, *underspecification* (e.g., Reyle 1993; Pinkal 1996; Dalrymple et al. 1997) and *optimality theory* (Prince and Smolensky to appear; Kager 1999). Both frameworks will be introduced briefly in this section.

3.1 The framework of underspecification

In the framework of underspecification, semantic representations *describe* fully specified meanings of linguistic expressions (rather than *denoting* them). Descriptions that are too unspecific to single out a fully specified meaning are compatible with a whole set of such meanings. If this set equals the set of readings of an ambiguous expression, the unspecific description captures the meaning of this expression exhaustively and non-disjunctively. (8) is an candidate for this analysis:

(8) daß Max alle Fenster aufmachte

In (8), the scope between CAUSE and $\forall$ is open. Apart from the reading ('for every window: Max opened it') it has the reading 'Max brought it about that all windows were open'. This reading is dispreferred, hence shows up only in special contexts, e.g., if the first reading is explicitly denied:

(9) Erst war nur die Hälfte aller Fenster im Bus auf, aber dann machte Max alle Fenster auf
'First only half of the bus windows were open, but then Max opened all windows'

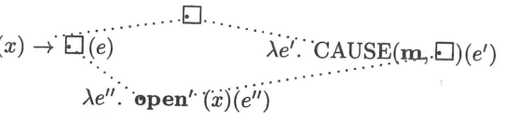
I.e., an underspecified semantic representation of (8) must leave open the scope of quantifier and CAUSE and be compatible with exactly two meanings, one for each of the two scoping possibilities.

The representation language used here is Constraint Language for Lambda-Structures (CLLS) (Egg et al. 1998). In CLLS, semantic representations are *constraints* on meanings. CLLS representations are based on *tree structures* that correspond to λ-terms. The notation of CLLS constraints is adapted to the needs of this paper. For the full details of CLLS, see Egg et al. (1998).

In the adapted notation, CLLS constraints describe λ-terms. They have three relevant parts: *fragments* of λ-terms ('LT fragments'), *holes* ('$\Box$'), i.e., positions in LT fragments where other fragments are inserted, and *dominance relations* that are indicated by dotted lines.

Dominance relations introduce underspecification. If in a constraint a hole in an LT fragment dominates another LT fragment, this expresses only that the first fragment outscopes the second. Other material may intervene between the two parts.

[2] Blutner and Jäger (1999) argue explicitly against representing the RR-ambiguity in terms of scope of *wieder*. However, their counterargument crucially depends on the assumption that reflexives like *sich ansiedeln* 'settle (intrans.)' are causative, which is not undisputed (see e.g. Wunderlich 1997).

(10) 

(10), the representation of (8), illustrates this adapted CLLS notation.[3] Such structures partially describe λ-terms. Holes represent parts of LT fragments that are not yet completely fixed. But when a hole dominates an LT fragment, the fragment is an (im-)proper part of the material represented by the hole. E.g., the scope of either operator in (10) is described by a hole, since it is not yet fixed. The bottom fragment $\lambda e''.\mathbf{open}'(x)(e'')$ is part of either scope. The hole at the top shows that the semantics of (8) as a whole is still open, but comprises either operator fragment.

λ-terms that are compatible with (10) stand for one of the readings of (8). One can derive these λ-terms by filling all holes (this must respect the dominance relations). If a λ-term can be derived in this way using only material present in the constraint, it is a *constructive solution* of the constraint.

(10) has two constructive solutions. Either operator fragment can fill the top hole, which forces the respective other operator fragment to fill the scope of the first one, with the bottom fragment as the scope of the second operator. These options give λ-terms for the two readings of (8):

(11) $\lambda e'\forall x.\mathbf{window}'(x) \rightarrow \mathrm{CAUSE}(\mathbf{m}, \lambda e''.\mathbf{open}'(x)(e''))(e')$

(12) $\lambda e'.\mathrm{CAUSE}(\mathbf{m}, \lambda e''\forall x.\mathbf{window}'(x) \rightarrow \mathbf{open}'(x)(e''))(e')$

3.2 Optimality theory

The crucial assumption of optimality theory (OT) is that well-formedness constraints are *soft* and may be violated. A ranking indicates the strength of these constraints. Apart from the set of constraints, there are two other main components of the grammar: a *generator* computes a number of competing outputs from a given input, an *evaluator* selects the preferred output according to the constraints. Output A is preferred over output B if the strongest constraint that B violates is stronger than the strongest constraint that A violates. If this criterion is not yet decisive, the output with the least violations of the strongest constraint violated by both A and B wins.

In the proposed application of OT to semantics, the input is an underspecified semantic representation. From this input, a resolution component generates the set of possible specifications of this input.[4] As evaluator, Blutner and Jäger's (1999) pragmatic principles are assumed: The 'I-principle' enforces that the most coherent ('cheapest') specification is chosen. The 'Q-principle' blocks specifications that could also be obtained with less complex input. (Hence, this application of OT comprises both production and comprehension perspective, see Blutner to appear.)

For the RR-ambiguity, Blutner and Jäger (1999) introduce the constraint that presuppositions should be kept as small as possible ('avoid accommodation [AvAcc]'), since processing presuppositions is rather costly (see van der Sandt 1992 for a formal account). I.e., the restitutive reading of RR-ambiguous expressions is the preferred one. They give the following explanation of the desambiguation of (1) by intonation.

(13) (a) daß Max alle Fenster wieder AUFmacht (restitutive reading)

(b) daß Max alle Fenster WIEder aufmacht (repetitive reading)

Both variants of (13) are assigned the same underspecified semantics. For both of them, the restitutive reading is preferred. (13a) is less complex than (13b) since it has an unmarked intonation, hence it is assigned the restitutive reading. This reading is blocked for the more complex (13b), which can only get the repetitive reading.

[3] Analyses differ w.r.t. the first argument of CAUSE: Dowty assumes a proposition for the cause here, others, an expression of type e (for the causer). Since nothing hinges on this difference for this paper, I have chosen the second option. Note also that in the following representations BECOME is omitted, since it invariably is placed in the same fragment as CAUSE, i.e., nothing can intervene scopally between these two operators.

[4] This treatment is similar in spirit though different in formalization to Blutner and Jäger (1999), who work with a dynamic semantics. For them, the semantic representation is the generator, which outputs a number of contexts from the input (another context). Semantic ambiguity, then, can be rephrased as the ability to change the context in different ways. Evaluating output contexts hence also indirectly evaluates the different readings of a semantic representation that have generated them.

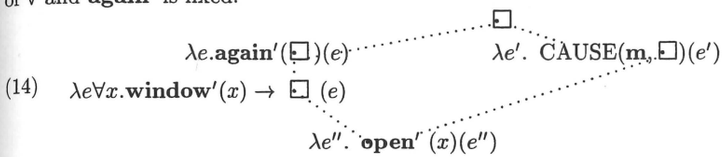
4 Derivation of the ambiguous representations

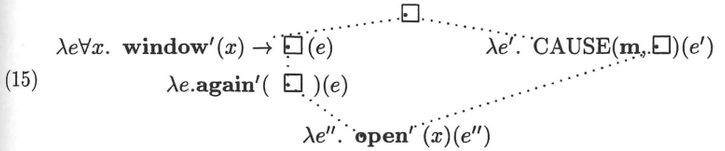
This section is devoted to the derivation of RR-ambiguities. The intuitions on (2) are that it has only three readings, although there are three scope bearers (**again′**, ∀, and CAUSE):

- Max opened every window, and he had done this to every window before (**again′** < ∀ < CAUSE; 'repetitive')
- Max brought it about that every window was open, and he had done this before (**again′** < CAUSE < ∀; 'repetitive'; see the discussion on (8) in section 3.1)
- all windows had been open before simultaneously, and Max restituted this state of affairs (CAUSE < **again′** < ∀; 'restitutive')

What these readings have in common is that **again′** outscopes ∀. Similar considerations on the readings of (1) reveal that is has three readings, too, whose common ground is wide scope of ∀ w.r.t. **again′**. This suggests an influence of word order on the semantic representation: roughly, a scope-bearing adverbial to the left of an NP outscopes this NP semantically. I.e., although word order influences the semantics of *wieder*-sentences, the order of object NP and *wieder* influences only the scope of the corresponding semantic contributions, which leaves room for both repetitive and restitutive readings for both word orders. This enlarges the repetitive/restitutive dichotomy (which focuses on the scope of **again′** and CAUSE). Note that this account does not precipitately determine whether a certain NP may occur in such a position. Hence, it fits in with analyses like Choi (1996) that present licensing conditions for such NPs.

The semantic representations in CLLS for (1) and (2) are (14) and (15), respectively. Each constraint has three constructive solutions, depending on the position of CAUSE, while the scope of ∀ and **again′** is fixed:

(14) 

(15) 

At this point, the task of semantic construction is over. The ambiguities of the representations (14) and (15) are suitable input to OT interpretation principles as proposed by Blutner and Jäger (1999). In section 5 I will show how to use these principles for the resolution of these ambiguities.

5 Resolution of the ambiguous representations

The resolution of examples like (1) and (2) that comprise in addition to CAUSE and *wieder* another (non-presuppositional) scope-bearing expression (here, a universal quantifier) is affected by the constraint (16) that is weaker than AvAcc:

(16) Don't insert semantic material in the semantic representation of a word ('no insertion [NI]')

(16) expresses a tendency for iconicity between syntax and semantics: semantic material that is introduced in terms of a syntactic atom (word) tends to reappear in the semantics as an indivisible whole. In particular, (16) is responsible for the rather pronounced preference of (11) over (12).

These constraints order the readings of (1) as represented in (15) in the following way:

scope relations	repetitive/restitutive	AvAcc	NI	intonation
∀ < CAUSE < **again′**	restitutive		*	stress on verb
CAUSE < ∀ < **again′**	restitutive		* *	stress on verb
∀ < **again′** < CAUSE	repetitive	*		stress on adverbial

Following Blutner and Jäger (1999), the unmarked intonation (here, stress on the verb) wins the competition for the preferred restitutive interpretation (CAUSE < **again'**), which enforces a repetitive reading (**again'** < CAUSE) for the marked intonation pattern with stress on the adverb. The preference for the first over the second reading in the above table can be put down to the fact that the former interpretation is more iconic to the syntax than the latter in that it violates NI only once. Only if the context is heavily biased against the first reading (e.g., by explicitly negating it, see the discussion on (8)) can the second reading get preference over the first. In sum, it is possible to derive the preferences on the interpretation of (2) with the help of OT constraints on the basis of an underspecified semantic representation.

6 Conclusion and further work

This paper discussed the possibility of modelling the derivation and resolution of ambiguities by constructing underspecified semantic representations that are suitable input for optimality theoretic principle. While the paper provides no more than a preliminary exploration of a combination of the two frameworks, the results look promising and merit further investigation.

Further potential applications of the approach comprise all cases in which an expression, although it applies syntactically or morphologically to a constituent as a whole, semantically pertains to only part of this constituent. All these cases can be treated analogously to the RR-ambiguity.

- modification of nomina agentis, as in *beautiful dancer* 'person that dances beautifully'
- aftermath modification, as in *leave for two hours* 'go away and be away for two hours'
- *un*-prefixation, as in *unkind* and *untie* (the meaning of the prefix is the same in both cases, viz., $\lambda P \lambda e. \neg P(e)$, the 'reversative' effect for *untie* emerges by inserting this meaning within the meaning of *tie*, below its BECOME operator)

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Cross-linguistic Semantics of Weak Pronouns in Doubling Structures

Javier Gutiérrez-Rexach
The Ohio State University

1. Introduction

Prosodically weak pronouns or clitics obey certain restrictions when they occur in so-called "clitic doubling" constructions. I claim that these restrictions are semantic in nature and can be properly characterized in GQ Theory. The analysis covers a wide array of data in Spanish and is extended to account for clitic doubling phenomena in other languages (Romanian, Greek, and Northern Italian dialects). An instance of a clitic doubling construction is a sentence in which a pronominal third person clitic is associated with a noun phrase which seems to be saturating the same argument as the pronominal element. In this sense, the clitic "doubles" the associated noun phrase, as illustrated in the following example from Spanish:

(1) Juan *le* dio el libro *a Pedro*
Juan to-him gave the book to Pedro 'Juan gave the book to Pedro'

Clitics will be treated here as denoting the same kind of quantifier functions as strong pronouns. These are determiner functions inherently restricted to context sets (Westerståhl 1985; van der Does 1995). Generalized quantifiers are arity reducing functions in general: functions mapping a n+k-ary relation to a n-ary relation (Keenan and Westerståhl, 1997). Thus, a pronominal clitic is a prosodically weak expression denoting a function mapping a set (the context set argument) to an arity reducer. Using Keenan's (1989) terminology for generalized quantifiers based in his semantic case theory, we can define the following (writing E to denote a universe, and $[A \rightarrow B]$ for the set of functions from A to B):

Definition. Let α be a clitic expression. Then,
(i) if α is [+*nom.*], $[\![\alpha]\!]$ is a function $F \in [\mathcal{P}(E) \rightarrow [\mathcal{P}(E) \rightarrow 2]]$
(ii) if α is [+*acc.*], $[\![\alpha]\!]$ is a function $F \in [\mathcal{P}(E) \rightarrow [\mathcal{P}(E^2) \rightarrow \mathcal{P}(E)]]$
(iii) if α is [+*dat.*], $[\![\alpha]\!]$ is a function $F \in [\mathcal{P}(E) \rightarrow [\mathcal{P}(E^3) \rightarrow \mathcal{P}(E^2)]]$

In non-doubling constructions, the context set is determined by discourse principles. In clitic doubling constructions, the context set is determined by (retrieved from) the denotation of the doubled expression. In the discourse in (2), the context set of *la* is not $GIRL \cap CAME\_IN$ but rather MARÍA:

(2) Una chica entró. Pedro la vio a María
a girl came-in. Pedro her saw to María
'A girl came in. Pedro saw María'

Following Keenan and Westerståhl's (1997) notation, I use AR$< -k >$ to indicate that a generalized quantifier is an arity reducing function from n+k-ary relations to n-ary relations. The denotation of a clitic doubling expression in which the clitic is an accusative proform is determined as follows:

(3) Let $\alpha_{d/acc}$ be an accusative doubling clitic expression and α_{acc} its non-doubling counterpart. Then, for all $C \subseteq E$, $R \subseteq E^2$, $Q \in AR < -1 >$
$[\![\alpha_{d/acc}]\!](C)(R)(Q_{acc}) = [\![\alpha_{acc}]\!](C)(R)$ & $C \in WITNESS(Q_{acc})$

An accusative clitic doubling expression denotes a function that maps a context set to an arity reducer which, in turn, combines with a generalized quantifier and yields an arity reducer whose context set is a witness of the "doubled" generalized quantifier. When the doubling clitic is a dative clitic, the associated quantifier is the dative extension of a generalized quantifier. Thus, there has to be a matching in semantic case between the clitic function and the associated quantifier. In general, for an arbitrary extension i of a generalized quantifier (where nominative corresponds to the first case extension, accusative to the second extension, dative to the third extension, etc.), the associated i-th extension of the doubling clitic can be defined as follows:

(4) For $1 \leq i \leq n$, let $\alpha_{d/i}$ be the i-th extension of a doubling clitic expression and α_i its non-doubling counterpart. Then, for all $C \subseteq E$, $R \subseteq E^n$, $Q_i \in AR < -1 >$
$[\![\alpha_{d/i}]\!](\mathrm{C})(\mathrm{R})(\mathrm{Q}_2)...(\mathrm{Q}_i)...(\mathrm{Q}_n) = [\![\alpha_i]\!](\mathrm{C})(\mathrm{R})(\mathrm{Q}_2)...(\mathrm{Q}_{i-1}), (\mathrm{Q}_{i+1})...(\mathrm{Q}_n)$
& $C \in WITNESS(Q_i)$

The above definition predicts that the interaction between the doubling clitic and the associated quantifier is always identical. Nevertheless, this is not the case in Spanish. In general, a dative clitic may double the dative extension of any generalized quantifier. Contrastingly, not all generalized quantifiers can be doubled by an accusative clitic. The associated quantifier in an accusative clitic doubling construction satisfies the following requirement: it has to be a principal filter. I will call this restriction the **Principal Filter Constraint**. Recall that a generalized quantifier Q over E is a *principal filter* iff there is a non-empty set $A \subseteq E$, such that for all $B \subseteq E$, $Q(B) = 1$ iff $A \subseteq B$. The set A is called the *generator* of Q. In accusative doubling constructions, the context set of the pronominal clitic function is the generator of the associated quantifier:

(5) Let $\alpha_{d/acc}$ be an accusative doubling clitic expression and α_{acc} its non-doubling counterpart. Then, for all $C \subseteq E$, $R \subseteq E^2$, $Q \in AR < -1 >$
$[\![\alpha_{d/acc}]\!](\mathrm{C})(\mathrm{R})(\mathrm{Q}_{acc}) = [\![\alpha_{acc}]\!](\mathrm{C})(\mathrm{R})$ & $C = GEN(Q_{acc})$

The examples in (6) are well-formed, whereas those in (7) are not. This is due to the fact that the noun phrases *todos los/esos estudiantes* 'all the/those students', *cada uno de los estudiantes* 'each one of the students,' and *Bill y Joe* 'Bill and Joe' denote principal filters. On the other hand, *muchos/varios estudiantes* 'many/several students', do not denote principal filters.

(6) Los encontraron a todos los/esos/cada uno de los
them-fem. found-they to all the/those/each one of the
estudiantes/Bill y Joe
students/Bill and Joe
'They found all the/those/each one of the students/Bill and Joe'

(7) *Los engañaron a muchos/varios estudiantes
*them fooled-they to many/several students
'They fooled many/several students'

There are quantifiers that are inherently principal filters (universals, definites and proper names) because they always have a generator. Other quantifiers,

such as existentials, numerals and to a lesser extent "vague" quantifiers (*many, few*) may denote principal filters in certain contexts. When the principal filter reading is forced, ie. when the speaker is referring to a particular group, doubling becomes felicitous (8a). Similarly, the presence of a doubling accusative clitic forces the associated existential quantifier to be a principal filter. It is forced to behave like a definite in that context (8b). [1]

(8) a. Las vi a ?pocas/ unas pocas niñas
them saw-I to ?few/ a-pl. few girls 'I saw few/a few girls'

b. Juan las vio a dos niñas
Juan them saw to two girls 'Juan saw (the) two girls'

Increasing and decreasing cardinal determiners that are positive (Keenan 1995; Keenan and Westerståhl 1997) [2] are accusatively doubled only when they are interpreted as principal filters. In this case they are non-monotonic. Overt partitives can be doubled too, and the partitive quantifier is interpreted as a principal filter.

(9) Los engañaron a muchos de los estudiantes
them fooled-they to many of the students
'They fooled many of the students'

Spanish bare plurals cannot trigger a principal filter reading (they can only have an existential non-definite reading). The prediction that follows from this property of bare plurals and the characterization of clitic doubling so far is that accusative clitic doubling of bare plurals is impossible, because this would force bare noun expressions to denote principal filters. This is indeed the case: the partitive bare plural *alcaldes de las ciudades costeras* 'majors of the coastal cities' cannot be doubled by an accusative clitic.

(10) *Los eligieron a alcaldes de las ciudades costeras
*them elected to majors of the cities coastal
'They elected majors of the coastal cities'

Dative clitic doubling is not subject to the Principal Filter Constraint. Both filter denoting and non-filter denoting noun phrases are allowed in doubling constructions with *le*. The behavior of existential and numeral determiners under dative clitic doubling follows the expected pattern. The principal filter and the standard (non-definite) interpretation are possible. [3]

[1] Characterizing the doubled quantifiers by the property of being a "strong" indefinite would not give the correct result. This is because the specific, partitive and presuppositional readings of indefinites (the readings usually covered under this label) do not necessarily entail principal filterhood of the quantifier. On the other hand, sentence (8b) is true if and only if there is a group of two girls such that Juan saw those two girls.

[2] A determiner function D is positive iff for all $A \subseteq E$, the quantifier function D(A) always maps the empty set to 0.

[3] In some circumstances the principal filter constraint is not sufficient to account for all cases of accusative doubling. More concretely, when there are two quantifiers belonging to the same class (existentials, universals or negative quantifiers) which may satisfy the Principal Filter Constraint, only the context dependent quantifier may be doubled. We may say that in this cases an additional Context Dependence Constraint has to be satisfied. For instance, Sp. *todos los hombres* 'all-masc.pl. the men' may be doubled but *todo hombre* 'every man' may not.

2. Accusative doubling in Romanian and Greek

Clitic doubling constructions in Romanian are similar to their Spanish correlates in many respects. The only difference is that if a quantifier expression denotes a principal filter in Romanian, then it has to be doubled obligatory. The proper name *Popescu*, the definite quantifier *cînele lui Popescu* 'the dog of Popescu' (63). The universal quantifiers *to ti* 'all' and *to ti copiii* 'all the children' in (64) and (65) are also principal filters, so they trigger doubling obligatorily.

(11) L-am văzut pe Popescu/cînele lui Popes./pe to ti copiii
him-have(I) seen to Popescu/dog-the of Popes./to all children-the
'I have seen Popescu/Popescu's dog/all the children'

Parallel to the Spanish case, generalized existential or intersective quantifiers (Keenan, 1995) may be doubled only when they denote principal filters. Clitic doubling disambiguates definite vs. non-definite readings of existential determiners and, again in parallel with Spanish, it is incompatible with subjunctive mood in a modifying relative clause.

In Greek, the class of quantifiers that can be doubled is more restricted. Only genuine definites (noun phrases that always denote principal filters) are doubled by an accusative clitic. Therefore, proper names, definite descriptions, universal quantifiers and demonstratives occur in accusative doubling constructions (Schneider-Zioga 1994).

(12) Tin-idha tin Maria/tin kopella
her-saw-I the Maria/the-acc girl
'I saw Maria/the girl'

Existential quantifiers cannot participate in (accusative) clitic doubling constructions (Anagnostopoulou and Giannakidou 1995). Bare plurals and proportional determiners such as *perisoterous* 'most' cannot participate in these constructions either. In Greek, only a subset of the quantifiers that can denote principal filters is doubled: those quantifiers headed by co-intersective determiners. We say that a function D $\in [\mathcal{P}(E) \rightarrow [\mathcal{P}(E) \rightarrow 2]]$ is *co-intersective* iff $\forall A, A', B, B' \subseteq E$ $A - B = A' - B'$ then D(A)(B) = D(A)(B).

3. Doubling and negative quantifiers

Let us now consider the behavior of Spanish *ningún* 'no' and *ninguno de los* 'none of the' in accusative doubling constructions. The simple negative quantifier *ningún* 'no' cannot occur in accusative doubling constructions but the quantifier *ninguno de los* 'none of the' can, as illustrated in (13):

(13) No lo he visto a *ningún político/ ninguno de los políticos
not him have-I seen to *no politician/ none of the politicians
'I have not seen any of thr politicians'

In this case, the difference cannot be related to the property of principal filterhood since neither *ningún* nor *ninguno de los* denote a principal filter. The only difference between the determiner functions NINGÚN and NINGUNO DE LOS is that the first argument of the latter is restricted to a context set C. Let A, B, C $\subseteq$ E. Then, NINGÚN(A)(B) = 1 iff A $\cap$ B = $\emptyset$; NINGUNO DE LOS (A)(B) = 1 iff (C $\cap$ A) $\cap$ B = $\emptyset$. The quantifiers NINGÚN(A) 'NO(A)' and

NINGUNO DE LOS(A) 'NONE OF THE (A)' denote principal ideals. We say that a generalized quantifier Q over E is a *principal ideal* iff there is a non-empty set $A \subseteq E$, such that for all $B \subseteq E$ $Q(B) = 1$ iff $B \subseteq A$. The set A is called the *generator* of Q. The principal ideals NINGÚN(A) 'NO(A)' and NINGUNO DE LOS(A) 'NONE OF THE (A)' are generated by the set ¬A. Thus, it is still possible to recover the set A (the complement of ¬A), although not as the generator of a principal filter, but rather as the complement of the generator of the principal ideal. One may hypothesize that the set is recovered not by direct semantic inference from the denotation of the quantifiers. Were this the case, doubling of principal ideals would be possible without further restrictions. The above contrast shows that the retrieval of the complement set of the generator of the principal ideal is only possible when the set is already presupposed, ie. when the function denoted by the determiner expression is restricted to a context set. This is the case of NINGUNO DE LOS (A) 'NONE OF THE (A)' where the presence of the definite determiner *the* forces the partitive or presuppositional reading.

Nominative clitic doubling in the Northern Italian dialects Trentino and Florentino is also sensitive to the semantic property of having a generator. In Trentino and Florentino, an agreeing nominative clitic may double a subject, if and only if, the subject denotes either a principal filter or a principal ideal. In the case of principal ideals, there is an additional constraint: the quantifier has to be restricted to a context set, ie. it has to be a presuppositional or partitive quantifier.

4. Clitic doubling in questions

The interaction of clitic doubling and interrogative quantifiers in questions confirms some of the claims that have been made so far. There is an important difference between the Spanish *wh*-words *quién* 'who' and *cuál* 'which one': the former cannot be doubled by an accusative clitic whereas the latter can.

(14) ¿A cuál/*quién lo han matado?
to which/*who him have-they killed
'Which one did they kill?'

In Gutiérrez-Rexach (1997), it is proposed that the quantificational expressions *quién* and *cuál* are interrogative generalized quantifiers: functions from sets of individuals to questions. Let $A, X \subseteq E$. Then, QUIÉN $\in [\mathcal{P}(E) \rightarrow [_q\mathcal{P}(E) \rightarrow 2]]$ and QUIÉN$(A)(X) = 1$ iff $PERSON \cap A = X$. Let $A, C, X \subseteq E$. Then, CUÁL $\in [\mathcal{P}(E) \rightarrow [\mathcal{P}(E) \rightarrow [_q\mathcal{P}(E) \rightarrow 2]]]$ and CUÁL$(C)(A)(X) = 1$ iff $C \cap PERSON \cap A = X$. The difference between QUIÉN 'WHO' and CUÁL 'WHICH ONE' is that the latter, but not the former, is restricted to a context set.

The difference between accusative and dative clitics emerges again: dative clitics may double any argument interrogative quantifier, whereas accusative clitics impose a stronger condition on the doubled quantifier. The quantifier has to be context dependent, ie. restricted to a context set argument. In sum, there is an asymmetry between doubling structures involving declarative and interrogative quantifiers. When an accusative clitic doubles a declarative quantifier, the Principal Filter Constraint and, in certain cases, the Context Dependence Constraint have to be satisfied. On the other hand, when the

doubled element is an interrogative quantifier, the constraint which is at stake is the Context Dependence Constraint: only interrogative quantifiers restricted to context sets may be doubled by an accusative clitic.

Dobrovie-Sorin (1990) observes a related contrast in Romanian. Doubling of the accusative interrogative quantifiers *cine* 'who'; *ce* 'what' or of an interrogative quantifier headed by *ce* is not possible, whereas doubling of the accusative interrogative quantifier *care* 'which one' or of the interrogative quantifier headed by the interrogative determiner *care* 'which' is obligatory. The difference between Romanian and Spanish is that in Romanian context dependent interrogative quantifiers trigger accusative clitic doubling obligatorily, whereas non context dependent interrogative quantifiers block it.

5. Conclusion

The nature of the dependence between a pronominal clitic and its quantifier associate is shown to be semantic in nature and to obey very precise restrictions that can be accurately formulated in Generalized Quantifiers Theory. The analysis of clitics as contextually restricted functions and of clitic doubling as the retrieval of a context set argument from a generalized quantifier lends itself to a treatment of this fundamental dependence as a family of related conditions on context set retrieval.

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Substructural Logic: a unifying framework for second generation datamining algorithms

Erik de Haas & Pieter Adriaans

Syllogic & University of Amsterdam

Abstract

In this paper we propose a framework for data mining algorithms based on a system of substructural logic. We show the connections between data mining, inductive logic programming and grammar induction. Furthermore we present a small family of substructural logics that can represent modern complex information systems. This small family of substructural logics on its turn will facilitate the design of efficient datamining algorithms using techniques from the field of inductive logic programming.

1 Introduction

Traditionally the inductive algorithms used in data mining work on tabular (relational) data sets. While in data and information representation practice there is a shift from tabular (relational) data representation towards a representation in more complex structures, there is also a new generation of datamining algorithms emerging. New data mining techniques are developed to process complex information structures like object oriented structures, strings (in relation to languages), and even multi media data. Examples of these developments are the work on the connection between datamining and language learning ([1]), and the work on datamining on complex information structures as done in multi relational datamining ([2]). We call this phenomenon *second generation datamining.*

The processing of more complex structured data calls for new algorithms. The inductive algorithms used for datamining on tabular (relational) structures are theoretically impaired with the computational complexity of full first order predicate logic. This is a problematic issue if one designs algorithms for induction on more complex structures then flat relations. This observation suggests that we need to found the structures on which we do datamining on a system with much better computational properties. This complies with the broader trend in logic in computer science that suggests that one needs to find logics tailored more closely to the application domain than a general language as full first order predicate logic [3].

In the logic community people have analyzed the landscape of substructural logic and have found systems with nice theoretical qualities that have fairly rich expressive power. For example in relation to grammar induction (data mining on strings) the observation is proper that the Lambek calculus is a substructural logic. For representation of complex information structures a substructural modal

logic is proposed in [4] (and [5]) that expresses the core features of Object Oriented design and database languages like the industrial standard language UML ([6]).

In this paper we propose a direction for designing algorithms for second generation datamining. We exploit the close connections between datamining and inductive logic programming (ILP). We will use a variety of substructural logics and ILP techniques for designing ways to do data mining on complex structures. We introduced the notion of *substructural logic programming* in [7]. In this paper we will present two important links in our research program:

- the connection between a small family of substructural logics and a complex data representation language resembling UML, and
- the use of substructural logic in ILP for datamining purposes.

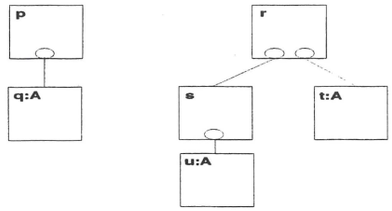
2 Substructural logic for UML like information modeling languages

The language we present below is called *the language of categorial graphs* ([1], [4], [5]). This language talks about essential properties and aspects of objects and has graphical and textual expressions. We will present the meta language for the categorial graph language that denotes direct translations of the graphical and textual constructs. The meta language is part of the traditional way of constructing denotational semantics for programming languages The meta language for the language of categorial graphs is a language with a substructural calculus based on the traditions of modal and linear logic. The meta language of categories has the following features:

- *Expresses propositions on the* aspects *(or complex structure) of an object using a modality.* I.e. a proposition about an aspect of an object is expressed with a modality (and modeled by an adjacency relation). The modality will have an existential character, and will be denoted by the $\Diamond$. This means we can express that an object has some properties without knowing the object totally. For example the complex objects[1] p, r and s in the picture below will all be of type $\Diamond A$. If we want to talk about a directed complex (adjacency) structure of an object, i.e. about the first adjacent, the second adjacent, etc. etc., we need to label the modal adjacency operator: $\Diamond_1, \Diamond_2, \Diamond_{\text{role}}$, etc.. Note that we may use symbolic names as labels.

[1] A note on the informal notation for an object: the structure of a complex object is denoted by a box using an circle as placeholder for an adjacent object and a line from the placeholder to the box that denotes the adjacent. The label $a : A$ will mean 'object a of type A'.

- *Has a linear aggregation operation.* This means that we can express the 'taking together' of two objects resulting in a new complex object. For example if we have two objects a and b, and a has two adjacents c and d, b has an adjacent d, then their aggregation $a \cdot b$ will have three adjacents, once c and twice d.

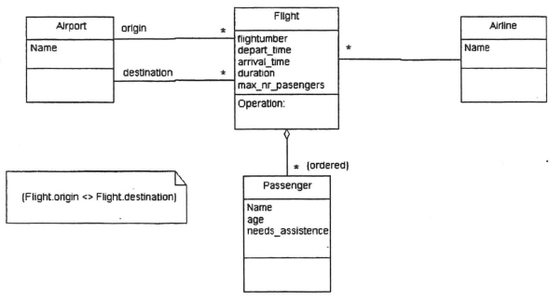


Definition 2.1 *(The meta language of categorial graphs) Let S_{CG} be a similarity type containing one unary modal operators $\Diamond$, $\Diamond^{-1}$ and ! together with the modal constant* **1**. *We define the language M_{CG} to be the pair $(S_{\mathsf{CG}}, Q_{\mathsf{CG}})$, where Q_{CG} is a set of propositional variables. The set $\Phi(M_{\mathsf{CG}})$ of formulas in M_{CG} is defined as usual, using next to the modal operators the connectives $\neg\_$, $\_*\_$, $\_\sqcap\_$, $\_\sqcup\_$,*

The $\Diamond$ and $\Diamond^{-1}$ modalities will talk about the adjacency relation R and its inverse; the ! will is the bang of linear logic, denoting unbounded linear multiplication and **1** models the empty (or unknown) objects. The * denotes aggregation or in other words the multiplicative or resource conscious conjunction[2]. The connectives $\sqcap$ and $\sqcup$ are respectively additive (*non* resource conscious) conjunction and additive disjunction. Finally the $\neg$ denotes (*non* resource conscious) negation.

For this language we developed a landscape of calculi that varies on the structural rules (exchange, weakening, contraction) for the modal (aspects), modal free (essential properties) and general formulas. In [5] we proved completeness for these calculi for a class of models called *discourse models*, which are formal descriptions of a complex structured object information system.

In the remainder of this section we describe an example of the use of this language. Consider the following simple model of a passenger flight in UML notation:



[2] i.e. $!A$ is $\mathbf{1} \sqcup A \sqcup A * A \sqcup A * A * A \sqcup \cdots$

The graphical syntax is translated into the logical meta language as follows:

$\text{Flight} \Rightarrow \Diamond\text{flight\_number}$
$\text{Flight} \Rightarrow \Diamond\text{depart\_time}$
$\text{Flight} \Rightarrow \Diamond\text{arrival\_time}$
$\text{Flight} \Rightarrow \Diamond\text{duration}$
$\text{Flight} \Rightarrow \Diamond\text{max\_nr\_passengers}$
$\text{Flight} \Rightarrow \Diamond_{\text{origin}}\text{Airport}$
$\text{Flight} \Rightarrow \Diamond_{\text{destination}}\text{Airport}$
$\text{Flight} \Rightarrow \Diamond!\text{Passenger}$
$\text{Flight} \Rightarrow \neg(\Diamond_{\text{origin}}\text{Airport} \sqcap \Diamond_{\text{destination}}\text{Airport})$

$\text{Airport} \Rightarrow \Diamond\text{name}$
$\text{Airport} \Rightarrow \Diamond^{-1}_{\text{origin}}\text{Flight}$
$\text{Airport} \Rightarrow \Diamond^{-1}_{\text{destination}}\text{Flight}$
$\text{Airline} \Rightarrow \Diamond\text{name}$
$\text{Passenger} \Rightarrow \Diamond\text{name}$
$\text{Passenger} \Rightarrow \Diamond\text{age}$
$\text{Passenger} \Rightarrow \Diamond\text{needs\_assistance}$

3 Inductive substructural logic programming and datamining

In the field of Inductive Logic Programming (ILP) a lot of work is done in developing strategies to find simple[3] and consistent hypothesis from a base of logical rules and axioms (facts). The traditional examples in this field deal with finding *logic programs* from a base of facts. More recently the ILP learning techniques are also used in datamining to find *interesting* patterns[4] from a base of tables (facts) and functional dependencies (rules).

The main problem of the ILP techniques is their computational tractability. Because First Order predicate logic (FOL) is enormously expressive, calculating with it is in general computational undecidable. This means that the search for an interesting hypothesis or relation could take forever, even when such an hypothesis exists. In this context the art of ILP could be seen as the ability to define strategies that come up with interesting hypothesis within reasonable computational resources. The following observations suggest an alternative route for using ILP strategies.

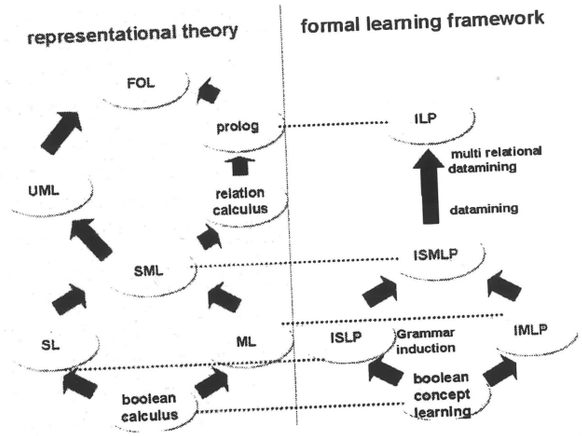
- datamining questions are questions on information system properties. Modern (Object Oriented) information system languages like UML are designed to express these kind of properties and an important part of these languages can be caught by a substructural logic.
- Inductive learning algorithms already exist and are studied for a substructural calculus, namely in language learning for grammar induction of context free grammars ([1]).

We propose to use ILP techniques for substructural and modal logics, i.e. Indcutive Substructural Modal Logic programming (ISMLP). This way we reduce the computational burden of ILP using FOL and use well studied logics with

[3] 'simple' in the sense that the hypothesis has a short description.
[4] nontrivial patterns that have a short description

nicer computational properties. We claim that for many purposes there exist substructural modal logics that are expressive enough to express the hypothesis and base of facts for ILP.

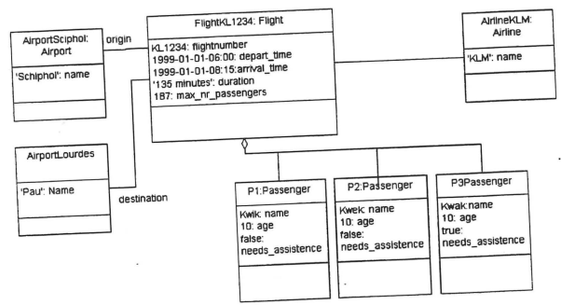
For datamining purposes the use of Inductive Substructural Modal Logic Programming (ISMLP) in put in context in the picture[5] below:



The general task for mining with ISMLP is similar to the task of ILP. Given Knowledge K and a set of examples E, we need to find a *consistent* and *interesting* pattern P such that

$$K \sqcap P \models E$$

Example 3.1 *Recall the example of the Flights above. The Theory for the inductive algorithm is the logic of categorial graphs. This theory is extended by background knowledge, which is the (translation of the in UML denoted) model of flights. Consider the facts (descriptions of objects, which are instances of the classes from the UML diagram) of the following kind (homomorph to the class diagram):*



[5] SL = substructural logic; ML = modal logic; SML = substructural modal logic; ISLP = inductive substructural logic programming; IMLP = inductive modal logic ptogramming.

$$\text{essentials/type assertions} \begin{cases} \text{FlightKL1234} \Rightarrow \text{Flight} \\ \text{AirlineKLM} \Rightarrow \text{Airline} \\ \text{AirportSchiphol} \Rightarrow \text{Airport} \\ \dots \end{cases}$$

$$\text{aspects} \begin{cases} \text{FlightKL1234} \Rightarrow \Diamond \text{AirlineKLM} \\ \text{FlightKL1234} \Rightarrow \Diamond_{\text{origin}} \text{AirportSchiphol} \\ \dots \end{cases}$$

An interesting pattern to be found could be of the likes of

$$\mathit{Flight} \sqcap < \text{destination} > \text{AirportLourdes} \Rightarrow \Diamond(\text{Passenger} \sqcap \Diamond \text{needs\_assistance})$$

i.e. a flight to Lourdes is bound to have a passenger that needs assistance.

4 conclusion

We have shown that a modern data object oriented representation language as UML can be expressed in a substructural modal logic. This opens the way for using ILP techniques based on substructural modal logic for datamining. We position substructural logic a unifying framework for applying learning techniques in fields that have a substructural logic as their represenational theory. An other examples indicated in this paper is grammar induction for categorial grammars.

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Toward a unified analysis of DP Conjunction

Caroline Heycock
Theoretical & Applied Linguistics
University of Edinburgh

Roberto Zamparelli
Facoltà di Lingue
Università di Bergamo

1 Introduction

This paper presents a novel set of data on conjunction inside the noun phrase, and shows how this little-studied domain includes structures with readings which are unexpected under any current theory of the semantics of coordination. Moreover, these readings vary across languages in an interesting and systematic fashion.

In order to fit these facts into a general (and ultimately fully unified) theory of constituent coordination, we propose a new semantics for conjunction, and we deduce the cross-linguistic variation ¿from an independently motivated theory of the syntax-to-semantics mapping, in which a parametric difference exists in the way natural languages obtain the semantics of *number*.

Our theory assumes an analysis of noun phrases as 'DPs' (Abney 1987) embedding the lexical projection of the noun, NP, plus various intermediate *functional projections* (FPs). To the extent the analysis is successful, it supports the existence of a direct mapping between syntactically motivated functional heads and semantic functions, and speaks in favor of a tighter integration between syntactic and semantic approaches to language.

1.1 The semantics of conjunction

A long-standing issues in the analysis of conjunction is the problem of a unified semantic interpretation for *and*. The conjunction of DP arguments denoting individuals, as in (1a), seems on the face of it to suggest a treatment in terms of set union, or *i-sums* (Link 1983; Link 1987).

(1) a. [John and Mary] danced.
b. [John and Mary] met.

The conjunction of predicates, as illustrated in (2a–b), on the other hand, is straightforwardly handled as intersection.

(2) a. My uncle is [short and fat].
b. My ancestors were [short and fat].

This apparent contrast between arguments and predicates can to some extent be dissolved by interpreting DP arguments as generalised quantifiers, in which case (1a) can also be interpreted as involving property intersection. This leaves open the problem of non-Boolean cases like (1b), for which various solutions have been put forward (Hoeksema 1983,1988; Krifka 1990; Lasersohn 1995; Winter 1996).

1.2 Conjunction within the DP

Typically, semanticists working on coordination have concentrated on the conjunction of maximal (extended) projections (in the case of noun phrases, the entire DP). In this paper, we want to focus on the relatively little-studied case of nominal conjunction within the DP, illustrated in (3).

(3) [My [friend and colleague]] always sang too loud.

A typical assumption about the internal syntax and semantics of argument nominals is that the NP embedded in the DP is interpreted as a predicate (e.g. Higginbotham 1987; Longobardi 1994), which restricts a variable contributed by the determiner, at the DP layer.

(4) $[_{DP}$ the $[_{NP/predicate}$ doctor]]

If the conjunction in (3) is at the level of the NP predicate, we expect it to be interpreted as intersection. This reading, which we will call the *joint* reading, is indeed available:

(5) a. [My [friend and colleague]] was late.
b. [That [liar and cheat]] is not to be trusted.

There is however another, unexpected reading, in which such a conjunction is interpreted as denoting distinct individuals with distinct properties. We call this the *split* reading: some examples are given in (6). Note that the agreement on the main verb may disambiguate the two readings.

(6) a. [My [father and grandfather]] were both sailors.
b. [That [man and woman]] were still shouting at each other.

Searches on the British National Corpus have shown that this reading, far from being an idiomatic usage, is productive, and possible with all singular determiners. Moreover, the split reading (like the joint reading) is also possible in the *plural*:

(7) a. [My [parents and grandparents]] were all from Rome.
b. [Those [men and women]] were advancing on the barricades.

Here, the noun phrases denote pluralities of people, each of whom (in the most natural interpretation) has only one of the properties in the conjunction. Moreover, each property must be represented in the plurality, unlike the corresponding "or" cases ("*Those men or women*").

While there are other languages (including Dutch) which pattern with English in allowing both a split and a joint interpretation for the conjunction of singular count nouns, in a number of languages, including French, Spanish, German, and Italian, conjunction of singular count NPs within DP yields only the joint interpretation, the singular split interpretation being excluded (here and throughout this paper we exemplify with Italian):

(8) a. [L' [amico e collaboratore] di Gianni] è stato qui.
the friend and collaborator of Gianni is been here
Gianni's friend and collaborator was here.
b. *[Questo [soldato e marinaio]] sono buoni amici.
this soldier and sailor are good friends
This soldier and sailor are good friends.

The impossibility of the split reading for the conjunction of singular count nouns in a number of languages was noted already in Dowty 1988, but there is a further important piece of the puzzle: this contrast between English and e.g. Italian holds only in the singular. In Italian, as in English, conjunction of plural NPs within DP can have a split reading (modulo matching genders).

(9) [Questi [soldati e marinai]] sono buoni amici.
these soldiers and sailors are good friends

We thus have at least the following questions to answer:

1. What semantics for conjunction can capture the full range of DP-internal cases (both the joint and the split readings)?

2. What is the difference between English and Italian that gives rise to the contrast in the singular alone?

2 Conjunction as "set product"

Assuming that common nouns (and NPs) denote (intensional) properties, if conjunction was always intersection we would expect *man and woman* to behave just like *short and fat* in (2): that is, we would expect only a *joint* reading to be generally available. Allowing a union semantics for DP-internal *and* does not resolve the problem, as this would give instead the meaning of *this man or woman* (one person). The idea that D is a plural syntactically disguised as a singular leaves as a mystery the fact that a normal plural D is unacceptable:

(10) a. that man and woman
b. *those man and woman

The proposal that the construction is really coordination of full DPs with ellipsis of the second D fails in various ways: among others, it cannot explain why in this case (in contrast to e.g. gapping) ellipsis occurs with *and* but not with *or* (witness the ungrammaticality of the ellipsis in *I didn't like the concert: the performer or ??(the) piece was not so good*), and it would have to be restricted *ad hoc* to apply only in the plural in Italian. Dowty's (1988) proposal to solve the problem by stipulating a special non-compositional rule for conjunction, peculiar to English, that involves type-lifting the conjuncts, equally gives no way to account for the singular–plural difference found in Italian and, we believe, goes in the wrong direction in locating the cross-linguistic difference in the semantics of *and*.

We propose instead that a successful account of these data must rely on a crosslinguistically invariant semantics for conjunction, and must seek to locate the divergence in an independently motivated difference between the syntax and semantics of the nominals.

In what follows, we will assume that both singular and plural individuals can be rendered as *sets* (type $<e,t>$). Properties will be uniformly of type $<<e,t>,t>$, and GQs of type $<<<e,t>,t>t>$. Singular Ns and NPs will therefore denote *sets of singletons*, rather than simple sets of atomic entities. To capture the split reading, the denotation of the conjunction of two singular NPs must be a set of two-membered sets, each containing an element from each of the conjoined nominals. This result is produced by the operation of *set product*, which we propose as a candidate for the denotation of "and".

(11) **Set Product**
$\text{SP}(A^1, \ldots, A^n) =_{def} \{ X : X = a^1 \cup \ldots \cup a^n, a^1 \in A^1, \ldots, a^n \in A^n \}$

The operation takes a member from each set, and performs union. Given two conjuncts, (NP_i and NP_j in (12a)) with non-overlapping extensions (e.g. *man and woman*), set product returns a set of two-membered sets (12b).

(12) a. $\|NP_i\| = \{\{a\}, \{b\}\}, \quad \|NP_j\| = \{\{c\}, \{d\}\}$
b. $\|NP_i \textit{ and } NP_j\| = \text{SP}(\|NP_i\|,\|NP_j\|) = \{\{a,c\}\{a,d\}\{b,c\}\{b,d\}\}$

Further, since set product is defined in terms of union, if the two conjuncts do overlap, whether fully or partially (as in e.g. *friend and colleague*), the resultant set will also contain singletons, e.g. $\{c\}$ in (13b), from $\{c\} \cup \{c\}$.

(13) a. $\|NP_i\| = \{\{a\}\ \{b\}\ \{c\}\}$, $\|NP_j\| = \{\{c\},\ \{d\}\}$
b. $\|NP_i\ and\ NP_j\| = SP(\|NP_i\|,\|NP_j\|) = \{\{a,c\}\{a,d\}\{b,c\}\{b,d\}\{c,d\}\{c\}\}$

The set of such singletons is the *intersection* of the two conjuncts, needed for the *joint* reading.

The problem of excluding the split reading for conjunctions such as (8b) in Italian now boils down to the problem of filtering out of a denotation like (13b) all the non-singleton elements, whenever the conjuncts are singular. Evidence independent of coordination shows that this is indeed the result of two different strategies for obtaining the denotation of singular and plural in Italian and in English.

3 The Syntax/Semantics interface

3.1 The internal structure of the noun phrase

We assume the following syntactic structure for noun phrases (see Cinque 1993, Longobardi 1994, Zamparelli 1995), and adopt a principle which maps functional heads (here, *D*, *Num* and *Pl*) onto semantic operators (15):

(14) a. [DP *Det* [NumP *Num* [PlP (*Modifier*) [NP *Noun* (*Compl*)]]]]
b. [DP Those [NumP few/three [PlP interesting [NP papers]]]]

(15) **Semantic Composition of Functional Heads:**
Each functional projection F denotes a function over the meaning of its syntactic arguments.

First, all count nouns (and NPs based on them), whether singular or plural, denote sets of singularities. The difference between singular and plural is expressed by the feature [±PLUR] on N; this feature raises to some higher functional head, and triggers a particular semantic operation at that point.

Second, at PlP pluralities are constructed from the base denotation of the NP, where "constructing a plurality" means building the closure under Generalised Union of the set denoted by the NP (the $*$-*operation*)

(16) **Generalised Union:**

$$\bigcup(X) =_{def} \begin{cases} \iota y,\ y \in X & \text{if X is a singleton set} \\ y^1 \cup \ldots \cup y^n & \text{if } X = \{y^1 \ldots y^n\};\ \text{undefined otherwise} \end{cases}$$

(17) $\|[_{Pl}\ NP]\| = *\|NP\| = \{X : \exists Y \subseteq \|NP\|\ X = \bigcup(Y)\}$

Finally, Num regulates the cardinality of the PlP denotation, filtering from it all the elements with the wrong number of atoms.

(18) $\|[_{NumP}\ n\ PlP]\| = \{X : X \in \|PlP\| \text{ and } |X| = n\}$

3.2 Two routes to number

If we now consider how the difference between singular and plural DPs can be obtained in our system, two possibilities present themselves. It is our contention that both are available to natural languages.

The first possibility is that a +PLUR feature value on the NP triggers the application of the $*$-operator at PlP, while a -PLUR does not; in the latter case Pl is inactive and the NP denotation (a set of singularities) is passed up to NumP unaltered. ±PLUR doesn't play any semantic role higher than PlP. In the absence of an overt numeral in Num, no semantic filtering takes place at NumP (the projection is possibly absent). We call this the *PlP strategy*; the strategy exemplified by English.

The second possibility is that singular and plural are ways to partition the denotation delivered by the $*$-operator at PlP. In this case, ±PLUR raises up to Num; a Num head reached by a -PLUR value *preserves* only elements of cardinality 1; a Num head reached by a +PLUR value *removes* all elements of cardinality 1. We call this the *NumP strategy*; this is the strategy exemplified by Italian.

This divergence is responsible for various syntactic differences in the two languages; semantically, it predicts that English should preserve singular individuals in the denotation of plural DPs, a fact normally obscured by pragmatic factors, but which emerges in the possibility, for English but not for Italian, of *plural negation* ("*no boys arrived*", false if a single boy arrived) and *dependent plurals*:

(19) a. Unicorns have horns. (*En: one per animal*)
b. #Gli unicorni hanno (i) corni. (*It: only >1 per animal*)

3.3 The two strategies for number meet conjunction

Consider now how the two strategies interact with the idea that conjunction denotes set product. In a model with two noun phrases, NP_i and NP_j, as in (13)a, both English and Italian obtain the denotation in (13)b and pass it up to PlP. [1] In English, Pl will leave it unchanged (both Ns have -PLUR features). NumP is inactive: the denotation, pairs included, reaches D and functions as a restrictor for D, giving rise to the possibility of either joint or split readings in English.

In Italian, on the other hand, the -PLUR feature on the N heads raised across-the-board to NumP triggers the filtering away of all pairs arising from the conjunction, leaving only {c}, in our example. Hence, no split interpretation is possible.

As noted above, in the plural the two languages converge: Pl will apply the $*$-operator over the result of set product, but Num_{+PLUR} will not filter away any of the resulting pluralities.

4 DP coordination

When applied to FPs which may denote individuals or singular properties (DP and NumP), conjunction displays an additional restriction, the impossibility of 'collapsing' multiple pluralities as a result of the application of union. Thus, the DPs in (20) are not felicitous if only 4 people (1 both a friend and a colleague) came.

(20) a. [{the/those} 3 friends] and [{the/those} 2 colleagues] came.
b. [{the/those} [3 friends] and [2 colleagues]] came.

However, set product can successfully apply to conjoin DPs built on Ns with non-overlapping extensions. If DPs are taken to denote <*e,t*> individuals, we will assume that the 'Quine operator' Q ($\lambda x \lambda y(x = y)$) can lift them to <<*e,t*>,*t*> singular properties to which set product can apply:

(21) $\|John\ and\ Mary\| = SP(Q(\{j'\}),Q(\{m'\})) = SP(\{\{j'\}\}\{\{m'\}\})=\{\{j',m'\}\}$

The ι operator can then be used to lower the result onto an individual. If on the other hand DPs (are lifted to) denote <<<*e,t*>,*t*>*t*> GQs, the set product operation performs the union of each <<*e,t*>,*t*> property across the conjuncts. This operation does not introduce into the denotation of the conjunction any property which wasn't already present in each GQ. For instance, suppose John has property P but not Q, and Mary Q but not P. It follows that both John and Mary have

[1] We are adopting the assumption that coordination is "as low as possible," possibly some reflex of a principle of structural economy

the property P∨Q. But P∨Q is just what set product returns when combining P in ||John|| with Q in ||Mary|| using union.

This approach also predicts that (22a) will have the same meaning as (22b), whereas (22c) will be compatible with the arrival of all the men but very few women.

(22) a. Most men and women came.
b. Most men and most women came.
c. Most of the men and women came.

This is because there is no way to select most women-containing pairs without selecting man-containing pairs, and vice versa. In (22c), on the other hand, *most* applies to a mixed plurality of men and women, selecting, say, 'more than half' of its total content.

5 Conclusion and extensions

A close examination of DP-internal conjunction across languages has led to a semantics for "and" that generalizes also to the case of full DPs. The next step is to develop an account of predicate conjunction. Here, the split interpretation is available in both Italian and English for nominal, but not adjectival predicates:

(23) Those objects are {stars and planets / # close and far away}

This leads to the hypothesis that the split reading is blocked with adjectives because their subject is raised across-the-board from a predicate-internal position.

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Deconstructing Jacobson's Z

Gerhard Jäger
Zentrum für Allgemeine Sprachwissenschaft Berlin

1 Introduction

One crucial intuition behind the enterprise of model theoretic semantics can be summarized by the slogan "Language is one thing, and meanings are something different". In more technical terms, interpretation is seen as a mapping from an algebra of syntactic forms to an algebra of meanings, and these two algebras are sharply distinguished conceptually. (This does not entail that they are disjoint—expressions may refer to other expressions or even to themselves.) Variables, as they are commonly used, do not fit into this picture. On the one hand, variables are expressions, i.e. atomic elements of the syntactic algebra. On the other hand, under a Fregean conception of interpretation, meanings are functions from variable assignments to other objects. So variables are set-theoretic building blocks of the semantic algebra as well. Thus a variable free approach to the syntax/semantics interface has an *a priori* conceptual appeal.

At a first glance, the greatest obstacle to a variable free semantics for natural language is the phenomenon of anaphora. The Categorial literature contains a series of proposals to overcome this problem. Generally there are two possible routes here. By definition, anaphoric expressions re-use the meaning of another expression, their antecedent. So the interpretation of anaphors involves a multiplication of semantic resources. So it has to be decided whether this is due to the lexical meaning of the anaphoric expression or whether meaning multiplication is done in syntax. The former route is taken by Szabolcsi 1989 and Moortgat 1996a, while Hepple 1990, Jacobson 1999 and Jäger 1998 opt for the latter alternative.

The present paper offers a unifying perspective. Working within the framework of multi-modal Type Logical Grammar (cf. Kurtonina and Moortgat 1995; Moortgat 1997), anaphora resolution is broken into two aspects. Duplication of meaning is due to the lexical meaning of anaphors, while the non-local character of this process is taken care of in syntax and controlled by multi-modal techniques. So the present approach falls into the first group of theories mentioned above. However, it is shown that Jacobson's 1999 and Jäger's 1998 system each can be embedded into one version of the multimodal system. So the two approaches 'resolution in lexicon' and 'resolution in syntax' should be regarded as complementary rather than mutually exclusive.

2 Jacobson 1999

2.1 Combinatory presentation

According to Jacobson, the meaning of an anaphoric expression is a function from the meaning of its antecedent to its meaning in context. Applied to anaphoric pronouns, this comes down to the claim that they denote the identity function over individuals. Anaphoric expressions are coded as such in their syntactic category too. To this end, Jacobson introduces a novel type-forming connective. A sign of category A^B is an anaphoric expression which may be transformed into a sign of category B provided it finds a suitable antecedent of category B. For typographic reasons and to stress the similarity with the other two categorial slashes we use the notation $A|B$ instead of A^B. So an anaphoric pronoun receives category $N|N$. The semantic impact of "|" is similar to the other slashes; it creates a functor category. Jacobson's proposal is framed in the general setup of Combinatory Categorial Grammar. The behavior of the third slash is governed by two combinatory schemata.

First, an anaphoric "gap" may percolate upward in complex structures. This is formalized by a mixed version of the Geach rule plus a monotonicity scheme.[1] (The arrows "$\rightarrow$ is used as a meta-variable over "$\backslash$" and /.)

$$\frac{}{x : A \rightarrow B \Rightarrow \lambda yz.x(yz) : (A|C) \rightarrow (B|C)}\ \mathbf{G}$$

$$\frac{x : A \Rightarrow M : B}{y : A|C \Rightarrow \lambda z.M[(yz)/x] : B|C}\ M$$

Second, anaphoric dependencies are established by means of the scheme **Z**.[2]

$$\lambda yz_1 \cdots z_n w.xwz_n \cdots z_1(yw) : (A|C) \rightarrow B_1 \rightarrow \cdots \rightarrow B_n \rightarrow C \rightarrow D \Rightarrow x : A \rightarrow B_1 \rightarrow \cdots \rightarrow B_n \rightarrow C \rightarrow D \qquad (\mathbf{Z})$$

2.2 Multimodal decomposition

In this subsection, I will present an embedding of Jacobson's system into the general theory of structural control proposed in Kurtonina and Moortgat 1995. For reasons of space, a presentation of this framework has to be left out here. The interested reader is referred to the cited work and Moortgat 1997.

We assume the base logic to be **NL**, the non-associative Lambek Calculus. To start with, it is easy to see that in the presence of the residuation laws, the combinator **G** and Jacobson's monotonicity rule are jointly equivalent to the following inference rule:

$$\frac{X[x : A] \Rightarrow M : B}{X[y : A|C] \Rightarrow \lambda z.M[(yz)/x] : B|C}\ \mathbf{G'}$$

Likewise, **Z** is equivalent to the combination of the following rules:

$$\frac{X[x : A \circ Y[y : B]] \Rightarrow M : C}{X[x : A \circ Y[z : B|A]] \Rightarrow M[(zx)/y] : C}\ \mathbf{Z'}_1$$

$$\frac{X[Y[y : B] \circ x : A] \Rightarrow M : C}{X[Y[z : B|A] \circ x : A] \Rightarrow M[(zx)/y] : C}\ \mathbf{Z'}_2$$

In words, an anaphoric slot can travel up in a resource tree, and an anaphora-slash can be introduced on the right hand side of a sequent if it is c-commanded by an antecedent of the appropriate category.

Let us suppose for a moment that our base logic is not **NL** but **LP**, i.e. we have unlimited access to associativity and permutation. Then—as the reader may check herself—all three rules become derivable iff we expand $A|B$ to $B\backslash(B \bullet A)$. This makes sense intuitively; if we ignore linear order and hierarchical structure, a pronoun may be considered as something which consumes it antecedent, makes a copy of it, and returns it to its original position.[3] Under the strict resource management regime of **NL**, such a treatment fails due to the non-local character of the rules given above. To make it work, we have to add structural rules which give access to associativity and permutation, and we have to restrict these rules by means of modal control devices to avoid a collapse of the base logic into **LP**. This is achieved by the interaction postulates given in figure 1.

[1] Jacobson's original formulation is somewhat more restrictive, limiting the premise to results of the application of **G**.

[2] Jacobson limits the type C to N, but there doesn't seem to be a special motivation for this restriction.

[3] This intuition is at the bottom of the Linear treatment of anaphora in Dalrymple et al. 1997, who assign a pronoun the lexical entry $\lambda x.\langle x, x\rangle : N \multimap (N \otimes N)$.

Let us look at each postulate separately. We assume that all anaphoric expressions are lexically locked by some unary modality $\Diamond$. Postulate (P0) replaces such a modally marked resource by a place holder constant $\mathbf{t}$, while the unlocked anaphoric resource is attached to $\mathbf{t}$ by a binary product $\bullet_1$.[4]

$$\begin{array}{rcll}
\Diamond A & \longleftrightarrow & \mathbf{t} \bullet_1 A & (P0)\\
A \bullet (B \bullet_1 C) & \longleftrightarrow & \langle\nwarrow\rangle(A \bullet B) \bullet_1 C & (P1)\\
(A \bullet_1 B) \bullet C & \longleftrightarrow & \langle\nearrow\rangle(A \bullet C) \bullet_1 B & (P2)\\
A \bullet (B \bullet_1 C) & \longleftrightarrow & \langle\leftarrow\rangle((A \bullet_2 C) \bullet B) & (P3)\\
(A \bullet_1 B) \bullet C & \longleftrightarrow & \langle\rightarrow\rangle(A \bullet (C \bullet_2 B)) & (P4)\\
A \bullet_2 (B \bullet_1 C) & \longleftrightarrow & (A \bullet_2 C) \bullet_2 B & (P5)\\
A \bullet_2 \Diamond B & \longleftrightarrow & \Diamond_1(A \bullet_2 B) & (P6)
\end{array}$$

Figure 1: Interaction postulates

The postulates (P1) and (P2) move the second argument of $\bullet_1$ up in the tree, marking the nodes on its path with the unary modalities $\langle\nearrow\rangle$ and $\langle\nwarrow\rangle$, depending on whether the movement originated from the left or the right daughter. (P3) and (P4) move the second argument of $\bullet_1$ to the left (right) sister-node, changing the mode of combination from $\bullet_1$ to $\bullet_2$ and marking the path with $\langle\leftarrow\rangle$ ($\langle\rightarrow\rangle$). Thus (P0)–(P4) enable any resource marked with $\Diamond$ to enter a local $\bullet_2$-configuration with any c-commanding node, while its place of origin is marked with $\mathbf{t}$ and the path with appropriate arrow modalities. So an anaphor can approach any c-commanding antecedent. After resolution, this process can be reversed since all postulates work in both directions.

Anaphora resolution as such is modeled by Modus Ponens plus $\bullet_2$ elimination as in the **LP**-treatment sketched above. After putting back the resolved anaphor to its original location, the anaphora-modality $\Diamond$ is matched by a corresponding $\Box^{\downarrow}$ and thus cancelled. So the anaphora type $A|B$ is to be deconstructed as $\Diamond(B \backslash_2 (B \bullet_2 \Box^{\downarrow}A))$. A Curry-Howard term M with type $A|B$ is translated as $\lambda x.\langle x, Mx\rangle$. So under the present perspective, the meaning of a pronoun is $\lambda x.\langle x, x\rangle$, as in Dalrymple et al. 1997.

These postulates are already sufficient to make both instances of **Z'** derivable. The derivation of $\mathbf{Z'}_1$ is given in figure 2. There $Y'[\mathbf{t}]$ is used as shorthand for the structure that is exactly like Y except that all nodes dominating $\mathbf{t}$ are marked either with $\langle\nearrow\rangle$ or with $\langle\nwarrow\rangle$, depending on whether its left or its right daughter contains $\mathbf{t}$.

$$\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{}{A \Rightarrow A}\ id \quad \dfrac{X[A \circ Y[B]] \Rightarrow C}{X[A \circ Y[\langle\Box^{\downarrow}B\rangle]] \Rightarrow C}\ \Box^{\downarrow}L}{X[A \circ Y[\mathbf{t} \circ_1 \Box^{\downarrow}B]] \Rightarrow C}\ P0}{\cdots}\ P1/2}{X[A \circ (Y'[\mathbf{t}] \circ_1 \Box^{\downarrow}B)] \Rightarrow C}\ P1/2}{X[\langle\leftarrow\rangle((A \circ_2 \Box^{\downarrow}B) \circ Y'[\mathbf{t}])] \Rightarrow C}\ P3}{X[\langle\leftarrow\rangle(A \bullet_2 \Box^{\downarrow}B \circ Y'[\mathbf{t}])] \Rightarrow C}\ \bullet_2 L}{X[\langle\leftarrow\rangle((A \circ_2 A \backslash_2 (A \bullet_2 \Box^{\downarrow}B)) \circ Y'[\mathbf{t}])] \Rightarrow C}\ \backslash_2 L}{X[A \circ (Y'[\mathbf{t}] \circ_1 A \backslash_2 (A \bullet_2 \Box^{\downarrow}B))] \Rightarrow C}\ P3}{\cdots}\ P1/2}{X[A \circ Y[\mathbf{t} \circ_1 A \backslash_2 (A \bullet_2 \Box^{\downarrow}B)]] \Rightarrow C}\ P1/2}{X[A \circ Y[\Diamond(A \backslash_2 (A \bullet_2 \Box^{\downarrow}B))]] \Rightarrow C}\ P0$$

Figure 2: Derivation of **Z'**

The derivation of $\mathbf{Z'}_2$ is analogous except that we use (P4) instead of (P3).

To deconstruct the **G'**, a qualification concerning modal decoration is necessary. It was mentioned above that the unary modality $\Diamond$ serves to mark **lexical** types as being anaphoric. Anaphoric types that are constructed during derivation come without this kind of decoration. More generally, we assume that all negative occurrences of a type $A|B$ (in the sense of van Benthem 1991:75) are translated as $\Diamond(B \backslash_2 (B \bullet_2 \Box^{\downarrow}A))$—i.e. with modal marking—while positive occurrences of $A|B$ are mapped just to $B \backslash_2 (B \bullet_2 A)$. Since **Z'** only involved negative occurrences, the

[4] This device is taken from Moortgat 1996b.

derivation given above is not affected by this.
This taken in to account, **G'** is derivable as well provided anaphora resolution is able to deal with hypothetical antecedents. This is ensured by (P5). In the derivation in figure 3, we use the same notational convention as above and leave out obvious steps.
Since positive and negative occurrences of $A|B$ are translated differently, we have to make sure that the identity axiom for $A|B$ remains derivable. This is where postulate (P6) comes in (cf. figure 4).

$$\dfrac{\dfrac{\dfrac{}{C \Rightarrow C}\,id \qquad \dfrac{\dfrac{X[A] \Rightarrow B}{C \circ_2 X[A] \Rightarrow C \bullet_2 B}\,\bullet_2 R}{\cdots}\,P0\cdots5}{(C \circ_2 C \setminus_2 (C \bullet_2 \square^{\downarrow} A)) \circ_2 X'[\mathbf{t}] \Rightarrow C \bullet_2 B}\,\setminus_2 L, \bullet_2 L}{C \circ_2 (X'[\mathbf{t}] \circ_1 C \setminus_2 (C \bullet_2 \square^{\downarrow} A)) \Rightarrow C \bullet_2 B}\,P5}{C \circ_2 X[\Diamond(C \setminus_2 (C \bullet_2 \square^{\downarrow} A))] \Rightarrow C \bullet_2 B}\,P0/1/2}{X[\Diamond(C \setminus_2 (C \bullet_2 \square^{\downarrow} A))] \Rightarrow C \setminus_2 (C \bullet_2 B)}\,\setminus_2 R$$

Figure 3: Derivation of **G'**

3 Jäger 1998

In Jäger 1998 I followed Jacobson in extending the inventory of type forming connectives with | and assigning pronouns the lexical entry $\lambda x.x : N|N$. The system is formulated in the type logical version of Categorial Grammar while Jacobson is working in the Combinatory tradition. Besides, Jäger 1998 differs from Jacobson's proposal in assuming that precedence rather than c-command is the necessary and sufficient to license anaphoric relationships. This is motivated by considerations concerning inverse linking constructions, weak crossover, VP ellipsis and cross-sentential anaphora.

$$\dfrac{\dfrac{\dfrac{\dfrac{}{A \Rightarrow A}\,id \qquad \dfrac{\dfrac{}{A \Rightarrow A}\,id \quad \dfrac{}{B \Rightarrow B}\,id}{A \circ_2 \langle \square^{\downarrow} B \rangle \Rightarrow A \bullet_2 B}\,\square^{\downarrow} L, \bullet_2 R}{\langle_1 A \circ_2 \square^{\downarrow} B \rangle_1 \Rightarrow A \bullet_2 B}\,P6}{\langle_1 A \circ_2 A \setminus_2 (A \bullet_2 \square^{\downarrow} B) \rangle_1 \Rightarrow A \bullet_2 B}\,\setminus_2 L, \bullet_2 L}{A \circ_2 \langle A \setminus_2 (A \bullet_2 \square^{\downarrow} B) \rangle \Rightarrow A \bullet_2 B}\,P6}{\Diamond(A \setminus_2 (A \bullet_2 \square^{\downarrow} B)) \Rightarrow A \setminus_2 (A \bullet_2 B)}\,\setminus_2 R, \Diamond L$$

Figure 4: Derivation of the identity axiom

Accordingly, the counterpart of Jacobson's **Z**—the rule of use for |—is (equivalent to) the following (where $X[A][B]$ is a structure containing the substructures A and B in that order):

$$\dfrac{X[x : A][y : B] \Rightarrow M : C}{X[x : A][z : B|A] \Rightarrow M[(zx)/y] : C}\,|L$$

Jacobson's **G** and the monotonicity rule are both covered by the rule of proof

$$\dfrac{x : A \circ y : p \circ X \Rightarrow \langle x, y, M \rangle : A \bullet p \bullet B}{X \Rightarrow \lambda x.M : B|A}\,|R$$

The resulting logic is called $\mathbf{L}_{|}$.
The rule of proof is not without problems. To start with, it imposes a restriction on the form of the Curry-Howard term of the premise. In other words, the Curry-Howard labeling is not just a book keeping device here but an intrinsic part of the proof theory. As a consequence, it proved to be difficult to develop an appropriate model theory for this logic. Furthermore, the system crucially relies on the unrestricted availability of associativity.

One might wonder whether these limitations are really unavoidable. A careful examination of the linguistic applications reveals that the rule of proof for | can be replaced by the weaker rule **G'** given above without changing the linguistic impact in any way.
Given this, an suitable deconstruction of the the Jäger 1998 version of $A|B$ should make $|L$ and **G'** admissible rules. This can be done in a way very similar to the multimodal system given in the previous section. The only adjustment needed is to replace (P4), which admits forward binding, by the two postulates given in figure 5.
The derivation of **G'** given in figure 3 does not make reference to (P4), so it remains valid in the revised system. As for **Z**, observe that now, due to the absence of (P4), an anaphoric resource can only move up the c-commanding nodes that precede it. The extension with (P4.1) and (P4.2) furthermore admits to move this resource down to any node dominated by this c-commanding node (again accompanied by marking all traversed nodes with and arrow modality). This amounts to saying that an anaphoric resource may travel to any node that precedes its base position. Thus $|L$ becomes a derivable rule. The proof is schematically given in figure 6. There I adopt the notational convention that $X'[A][B]$ is exactly like $X[A][B]$ except that every node at the shortest path leading from A to B is marked by the appropriate arrow modality.

$$(A \bullet B) \bullet_2 C \longleftrightarrow \langle\swarrow\rangle((A \bullet_2 C) \bullet B) \quad (P4.1)$$
$$(A \bullet B) \bullet_2 C \longleftrightarrow \langle\searrow\rangle(A \bullet (B \bullet_2 C)) \quad (P4.2)$$

Figure 5: Revised Interaction postulates

$$\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{X[A][B] \Rightarrow C}{X[A][\langle \square^{\downarrow} B \rangle] \Rightarrow C}\,\square^{\downarrow} L}{X[A][\mathbf{t} \circ_1 \square^{\downarrow} B] \Rightarrow C}\,P0}{\cdots}\,P1/2/3/4.1/4.2}{X'[A \circ_2 \square^{\downarrow} B][\mathbf{t}] \Rightarrow C}\,\setminus_2 L, \bullet_2 L}{X'[A \circ_2 A \setminus (A \bullet_2 \square^{\downarrow} B)][\mathbf{t}] \Rightarrow C}\,P1/2/3/4.1/4.2}{\cdots}\,P1/2/3/4.1/4.2}{X[A][\mathbf{t} \circ_1 A \setminus (A \bullet_2 \square^{\downarrow} B)] \Rightarrow C}\,P0}{X[A][\Diamond(A \setminus (A \bullet_2 \square^{\downarrow} B))] \Rightarrow C}$$

Figure 6: Derivation of $|L$

While all relevant sequents that are derivable in $\mathbf{L}_{|}$ remain derivable under the translation given above, the multimodal system is more liberal. Notably, it interacts with quantification in an interesting way. The interaction postulates closely resemble (and are inspired by) the ones used in Moortgat 1996b to deal with quantifier scope. We can in fact replace Moortgat's deconstruction of the *in situ* binder $q(A, B, C)$ by $\Diamond((B/_1 \square^{\downarrow}{}_A) \setminus_1 C)$ in the present system.
Moortgat 1996a proposes to assign pronouns the type $q(N, N \setminus S, N \setminus S$. Under the deconstruction of | and q assumed here, the translation of the following sequent is derivable:

$$N|N \Rightarrow q(N, N \setminus S, N \setminus S)$$

So the present treatment of pronouns is not just a generalization of Jacobson's, but also of Moortgat's proposal. Likewise, the types $((N \setminus S)/N) \setminus (N \setminus S)$ and $(((N \setminus S)/S) \setminus (N \setminus S))/(N \setminus S)$, which are assigned to reflexives and pronouns respectively in Szabolcsi 1989, are derivable from the translation of $N|N$.
The multimodal reformulation of $\mathbf{L}_{|}$ presented in this section avoids all three shortcomings mentioned above. First, none of the logical rules or interaction postulates imposes any constraints on the Curry-Howard terms of the premises. So the applicability of sequent rules solely depends on the types. Second, no special requirements

on the structural properties of $\bullet$, the default mode of combination, are made. No special reference to associativity or other structural rules are made.
Finally, the multimodal system, as well as the one presented in the previous section, is easily supplied with a sound and complete model theory. An obvious candidate is interpretation of binary operators in ternary frames in the sense of Došen 1992 that was extended to unary modalities in Moortgat 1995 and to 0-ary modalities as the constant **t** in Moortgat 1996b. Interaction postulates are compiled into frame conditions using the algorithm given in Kurtonina 1995. The soundness and completeness proofs are entirely standard; the latter is done by constructing canonical models from the set of types.

4 Conclusion

To sum up, the multimodal treatment of anaphora proposed here offers a unifying perspective on previous proposals in two respects. First, the two non-local phenomena of quantifier scope and anaphora are treated by means of the very same modal licensing and control devices. Second, it generalizes several seemingly incompatible categorial treatments of anaphora from the literature. In particular, even though the binding force of anaphors is essentially due to their lexical meaning there, it also covers accounts like Jacobson's where binding is done in syntax.

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On the interpretation of IF Logic

Theo M.V. Janssen, Computer Science, University of Amsterdam

1 Introduction

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. A version of such games, introduced by J. Hintikka, is IF logic: independence friendly logic. It is described in a number of publications e.g. Hintikka (1996), Hintikka & Sandu (1997), Sandu (1993). In IF logic the quantifier $\exists y/x$ arises, which means that a value for y has to be chosen independent of the value for x, and the disjunction $\psi \vee/x \theta$ where a subformula has to be chosen independent of x. The language also has the set-variants $\exists y/W$ and $\psi \vee/W \theta$, where W is a set of variables.

Sandu provided a game theoretical semantics. Hintikka claimed that a compositional semantics for the logic would not be possible. However, Hodges has given a compositional interpretation (Hodges (1997*a*),Hodges (1997*b*)) which is equivalent on sentences. By doing so, Hodges clarified several aspects of the logic.

The semantics of Sandu and Hodges I consider not as completely satisfactory. In this paper, arguments will be given for this opinion, and an alternative will be sketched (which is *not* equivalent to the other proposed of semantics).

Since this paper is written to communicate the idea in a non-final stage, some limitations are obeyed:

1. Only the 'truth' of a sentence is considered, not 'falsehood'.
2. Negation is not incorporated in the fragment of the language.
3. Indexed relations, disjunctions or conjunctions are not considered.

We will follow Hodges' version of the language, writing $\exists y/x$ instead of $\exists y/\forall x$. Analogously we write $\exists y/W$. Following Hodges, the players are called ∃loise (female) and ∀belard (male). This has the advantages that pronouns can be used without the danger of confusion, and that the names reflect the choices the players make (in the situations arising in this paper): ∀belard makes the choice for $\forall$ and $\wedge$, and ∃loise for $\exists y$, $\exists y/x$, $\exists y/W$, $\vee$, $\vee/x$ and $\vee/W$. A formula is true if ∃loise has a winning strategy.

For variables bound by universal quantifiers always x's will be used, and for existential quantifiers y's.

Some examples which illustrate the aims of IF logic are given below. They are interpreted on the natural numbers (**N**).

1. $\forall x\, \exists y/x\, [x = y]$
   When ∀belard has chosen, ∃loise does not know the value of x, and therefore there it may happen that she selects another value. Hence ∃loise has no winning strategy, the formula is 'not true'.
   Also with $\neq$ instead of $=$, the formula is 'not true'.

2. $\forall x\, \exists y/x\, [y \leq x]$
   The strategy 'let y to be 0' is winning for ∃loise whatever ∀belard plays, hence the formula is 'true'.

3. $\forall x_1 \exists y_1 \forall x_2\, \exists y_2/x_1\, [x_1 < y_1 \wedge x_2 < y_2]$
   The choice of y_2 is independent of x_1, but may depend on x_2. A more familiar

representation of this example is by means of a branching quantifier:

$$\begin{pmatrix} \forall x_1 & \exists y_1 \\ \forall x_2 & \exists y_2 \end{pmatrix} [x_1 < y_1 \wedge x_2 < y_2]$$

The formula is true (on **N**). This formula is not expressible in first order logic, therefore it illustrates the power of IF logic.

2 The problem

Hodges has given a compositional semantics for IF logic, called 'trump semantics'. He discovered an example 1 which, to everyone's surprise, yielded 'true'. Below more examples with surprising results are given. Again, the interpretation is on **N**.

1. $\forall x \exists y_1 (\exists y_2/x)[x = y_2]$
   This resembles the first example in section 1, a vacuous quantifier $\exists y/x$ is inserted. Such a quantifier says that there is an element in the domain. One might expect that the information that the domain is not empty, is of no use in finding a y_2 independent of x. Surprisingly - Hodges warns the reader - the formula yields 'true' . The strategy ∃loise follows for $(\exists y_2/x)$ is to choose always y_2 to be equal to y_1. This strategy does not mention the value for x, and is, therefore, allowed. The strategy for $\exists y_1$ is to choose y_1 equal to x. This dependence is allowed because $\exists y_1$ has no slash. Hence $x = y_1$. Since $y_2 = y_1$ it follows that $x = y_2$. So by choosing this strategy, ∃loise always wins. The vacuous variable is used to transfer the value of x.

   This is not according to my intuition of independence. The value of y_2 is carefully chosen in such a way that it equals x, hence it is very dependent on x. If ∃loise uses y_1 to recall the value of x, that is, in my opinion, cheating because she is supposed *not* to use that value.

2. $\forall x[(\exists y/x)[x \neq y] \vee (\exists y/x)[x \neq y]]$
   According to my intuition, if you cannot find a y independent of x, you also cannot find it if you have the choice to find it on the left or on the right. But in trump semantics that is not the case. For instance, if $x = 3$, then ∃loise chooses left, and there she has the strategy always to choose 4. Otherwise ∃loise chooses right, and there she always chooses 3. In both cases the chosen disjunct is true. So this is a winning strategy, hence the formula is true.

   This example shows a remarkable property of trump semantics: $\phi \vee \phi$ is not in all contexts equivalent with ϕ.

   There are surprising variants of this formula. Finding a y independent of x which equals x is more difficult than finding one which does not equal x: replace in ϕ the $\neq$ by $=$ and the formula is no longer true. For an infinitely long disjunction with equalities the formula is true again.

3. $\forall x[x \neq 2 \vee (\exists y/x)[x = y]]$
   ∃loise has in trump semantics the following strategy: let y be equal to 2. Her strategy for the disjunction is as follows. If x is different from 2, she chooses left (the left side of the disjunction is then true), and otherwise she chooses right (which then becomes true by her choice for y).

   Recall that in the first example of section 1, ∃loise could not find a y independent of x such that $x = y$. According to my intuition that also

means that she cannot find an x in situations where she can deduce from the context that $x = 2$, because she is supposed *not* to use the value of x. Using this value is cheating.

Note that $\forall x[x = 2 \vee (\exists y/x)[x = y]]$ is 'not true' in trump semantics, whereas $\forall x[x = 2 \vee (\exists y/x)[x \neq y]]$ is 'true'; a surprising trio.

3 Discussion

The examples given above illustrate that although in trump semantics the strategy for $(\exists y/x)$ and $\vee/x$ indeed is not based directly on the value of x, any information about the value of x which can deduced from other sources may be used: the value of other variables (example 1), the form of other parts the formula (example 3), or strategies used in other parts of the formula (example 2). This indirect information can go that far, that the value of x is known, and than a strategy can be based upon that information (example 3).

The examples show that the results of trump semantics do not correspond with intuitions about independent choices. For these reasons, it is my opinion that trump semantics is not a formalization of 'informational independence', but of 'incomplete information'. It is not impossible that Hodges would agree with this opinion, because the title of his paper is 'Compositional semantics for a language of imperfect information', and *not* '... for a language of informational independence'.

The examples given before, illustrate that a choice independent of x should not be tailored to special (incomplete) information on x. In the alternative proposed in this paper is that the value for y should be suitable for all x. However, this must worked out carefully. One might be tempted to formalize independence by means of universal quantifier: $\exists(y/x)\phi \equiv \exists y \forall x \phi$. This is not correct. A counter-example (due to Hodges) is the IF-version of a branching quantifier (the last example in section 1). If we replace there $\exists(y/x)$ by $\exists y \forall x$ we get $\forall x_1 \exists y_1 \forall x_2 \exists y_2 \forall x_1 [x_1 < y_1 \wedge x_2 < y_2]$. This formula is not true because there certainly are x_1's greater than y_1 (note that the first quantifier became redundant).

4 The subgame approach

The basic idea of our approach is that subformulas are considered as subgames. Such a subgame can be played on its own. There are strategies for subgames, and some may be winning for ∃loise. Variables which do not occur in a subformula are of course not relevant for the winning strategies for the subgame. If a subgame starts with the quantor $\exists y/x$ the value chosen for y should work in all comparable situations. A winning strategy for a large game consists of winning strategies for the subgames. Below these idea's are worked out further, in a later version of the paper detailed mathematical definitions will be given.

The notion 'game' is generalized to arbitrary formulas. A game is a pair consisting of a formula (maybe with free variables), and a dependency set, which for each y indicates on which variables it depends. If the formula has free variables either an initial position is set up by the players (i.e. initial values for the free variables are chosen), or the values are given by previous moves in a

larger game. Next a move is played by which a subgame is entered.

∃loise may have a strategy which describes how she will react on moves of ∀belard. A strategy for $\exists y$ is a function that yields a value for y which has as argument the initial position of the subgame, likewise for $\vee$ yielding R or L. So variables which do not occur in the subformula, are not among the arguments of the strategy function. A strategy function for $\exists y/x$ is a function of the same kind, which obeys certain restrictions, to be given below.

Some of the strategies may have the property that they guarantee ∃loise a win, whatever ∀belard plays. Formulas for which there is such a strategy are 'true'. The winning strategies for $\exists y/x$ obey the following restrictions:

1. The strategy function does not have x as argument.
2. The strategy function does not have the y's as argument which depend on x. Otherwise the choice would depend indirectly on x.
3. The strategy also works when x has another value, provided the values of y's which depend on it are adapted. Likewise for those y's.

Analogous restrictions hold for $\exists x/W$, $\vee/x$ and $\vee/W$.

A winning strategy for an entire game is formed by a combination of winning strategies for its subgames. One might describe the situation as follows: associated with a (sub)game there is a shelf of strategies, and when a subgame is entered in a certain initial position, a plan is taken from its shelf which fits on that position, and it is followed until a new subgame is entered. This concept of a winning strategy means that not all conceivable strategies are available; only those which are built from strategies that would also work if the game was played in isolation or as subgame of another game.

Maybe it is useful to emphasize the distinction with other interpretations of 'independence':

1. It is not assumed that there are players who forget a value for a variable and may remember it later.
2. It is not assumed that there are teams of players in which for each new variable a new player is introduced who gets only partial information
3. It is not based on equivalence classes of information sets within its game tree.

One might say that in the present approach equivalence classes are introduced among the information sets in *all* games in which the subgame arises. We will not follow this line, and rather follow the track of 'subgames'.

5 Examples

Below examples are given which illustrate the kind of analysis arising with the subgame approach.

1. $\exists y/x\,[x \neq y]$
   No free y's arise, hence the dependency set is empty. Let us assume that this game is played with initial position $x = n$. Is there a winning strategy for ∃loise? A candidate is $y := n + 1$, which is winning in the given start position. But this is not winning for other values of x: if $x = n + 1$ the strategy $y := n + 1$ looses. Since there is no strategy which works for all values of x, there is no winning strategy for ∃loise in the given initial position $(x = n)$. Neither there is a winning strategy in any other initial position. A related argument holds for $\exists y/x\,[x = y]$

2. $\forall x\,\exists y/x\,[x \neq y]$
   The game starts with ∀belard choosing a value for x, say $x := n$. Then the subgame $\exists y/x\,[x \neq y]$ is played, from start position $x = n$. As we have seen in the previous example, there is no winning strategy for this subgame. Hence there is no winning strategy for the entire game. The formula is not 'true'.

3. $\forall x[\exists y/x\,[x \neq y] \vee \exists y/x\,[x \neq y]]$
   First ∀belard chooses, say $x = n$. Next ∃loise has to choose L or R. If she chooses L then she has to play a subgame for which she has no winning strategy. The same if she chooses R. So no strategy for $\vee$ brings her in a winning position. Hence she has no winning strategy for the entire game; the formula is not true.

   It may be instructive to consider the difference with trump semantics. There in the left game the strategy $y := 4$ was followed. Since it is only played with $x = 3$, the subgame was won. But this choice is not a winning strategy for the subgame because it does not work for all values of x. Therefore it can, in our approach, not be a part of a winning strategy in the entire game.

4. $\forall x_1 \exists y_1 \forall x_2\, \exists y_2/x_1\,[x_1 < y_1 \wedge x_2 < y_2]$
   This is the branching quantifier formula. First we consider its subgame $\exists y_2/x_1\,[x_1 < y_1 \wedge x_2 < y_2]$. The dependency information that holds here, is that y_1 depends on x_1. There is a strategy that gives ∃loise a win: $y_2 := x_2 + 2$. Furthermore, if x_1 has another value (say p), then the same strategy brings ∃loise a winning position, provided the value of y_1 is changed to $p+1$. This gives ∃loise a winning strategy that can be used for the entire game. After ∀belard's choice for x_1, she chooses $y_1 := x_1 + 1$, and after his choice for x_2, she follows the just described winning strategy for the subgame.

5. $\phi \equiv \forall x[x \neq 2 \vee \exists y/x\,[x = y]]$
   Consider the subgame $x \neq 2 \vee (\exists y/x)[x = y]$. For the right hand side of the disjunction there are no winning positions at all. For the left hand side there are many winning positions, but one is not winning: the position $x = 2$. So there is no strategy for $\vee$ which brings ∃loise from each initial positions in game $x \neq 2 \vee (\exists y/x)[x = y]$ into a winning position in some subgame. Hence there is no winning strategy for ϕ.

6. $\phi \equiv \forall x \exists y_1\, \exists y_2/x\,[x = y_2]$
   This example resembles the first example in the section 2. That was true because the value of y_1 was be used to transfer information about x. In the subgame approach a strategy for $\exists y_2/x$ cannot be based upon the value of a non occurring variable. As we have seen in the first example in this section, there is no winning strategy for $\exists y_2/x\,[x = y_2]$. Hence there is none for $\exists y_1\, \exists y_2/x\,[x = y_2]$. So ϕ is not true.

   The discovery that this formula is true in trump semantics was so shocking that Hintikka wrote that this was never intended. He informed us that in IF logic it was always silently assumed that all y-variables were slashed for the other y-variables in whose scope they directly occur (i.e. without intervening $\forall$ quantifiers). My conclusion would be that trump semantics does not reflect the originally intended semantics.

7. $\exists y_1 \exists y_2 [y_1 = y_2]$
   IF logic has classical predicate logic as sublanguage. On that fragment the game interpretation and the Tarskian interpretation yielded the same true sentences. Is that still the case when $\exists y_2$ is to read as $\exists y_2/y_1$? Then the strategy $y_2 := y_1$ is not available. ∃loise might follow the strategies $y_1 := n$ and $y_2 := n$. I do not know whether Hintikka considers these strategies to be independent (although changing the one evokes the same change in the other), or that he is willing to give up that predicate logic is a special case of IF logic. In the subgame approach ∃loise follows the strategy $y_2 := y_1$.

Summary

We argued that informational independence of a choice can be characterized by taking all games into consideration in which that choice arises.

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A Calculus for Direct Deduction with Dominance Constraints

Jan Jaspars, University of Amsterdam
Alexander Koller, University of the Saarland

Abstract. Underspecification has become a popular approach to dealing with ambiguity. An important operation in this context is *direct deduction*, deduction on underspecified descriptions which is justified by the meaning of the described formulae. We instantiate an abstract approach to direct deduction to dominance constraints, a concrete underspecification formalism, and obtain a sound and complete calculus.

1 Introduction

Over the past few years, *underspecification* has become a popular approach to dealing with some types of ambiguities, especially in semantics. It tries to avoid or postpone the combinatorial explosion of readings in a sentence with multiple ambiguities by specifying the set of readings with a single, compact *description*. Semantic processing, such as deduction, should then take place on the descriptions instead of all the readings; readings are only enumerated by need.

An essential operation that must be possible on underspecified descriptions for underspecification to be attractive is *direct deduction*: given an underspecified description, derive a description of logical consequences of the described first-order formulas. For example, it should be possible to make the following simple derivation without resolving the scope ambiguity in the first premise:

Every man loves a woman.
John is a man.

John loves a woman.

There has been some debate over the correct notion of underspecified entailment that a calculus for direct deduction should model [Rey95, vD96, Pin99], without reaching a clear conclusion so far. As a way out of this, [Jas99] proposed a very modular calculus on generic underspecified descriptions that is based on a semantics which can be tailored to make several different proof rules sound and complete.

In this paper, we adapt the calculus from [Jas99] to the language of *dominance constraints* [KNT98], a tree logic which has been used for underspecified descriptions [ENRX98] and whose formal properties are well understood. This combination is interesting from both perspectives: From the perspective of [Jas99], it's the first instantiation of the generic approach to a "real" underspecification formalism, and from the perspective of [KNT98], it provides a direct deduction calculus, and it illustrates the power of the tree description approach.

After illustrating the basic idea of underspecification in Section 2, we start by presenting the abstract, general calculus in Section 3. This is complemented by a brief introduction to dominance constraints in Section 4. We present the concrete calculus for dominance constraints in Section 5 and conclude in Section 6.

2 Underspecification

A notorious problem in natural language processing is that the number of readings of an ambiguous sentence grows exponentially with the number of ambiguities, increasing the cost of later processing steps by an exponential factor. Semantic underspecification attempts to tackle the problem of combinatoric explosion of readings

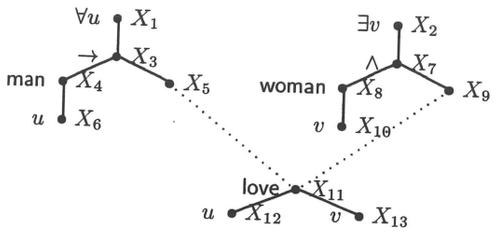


Figure 1: Underspecified description of the semantics of "Every man loves a woman".

by deriving from the syntax a single, compact *description* of the readings and working with descriptions for as long as possible. Direct deduction, then, is an operation on the descriptions that models deduction on the readings.

The new level of descriptions is usually called the *meta level* (ML), whereas the original level of (unambiguous) semantic representations is called the *object level* (OL). We will use predicate logic as the object language and dominance constraints as the meta language in this paper. To avoid confusion, we rename the OL connectives to $\underline{\wedge}$, $\underline{\forall}$, etc. Note that the abstract algorithm in Section 3 is independent of the exact choice of meta and object language.

An example for an underspecified representation can be found in Fig. 1. This graph describes the two readings of the sentence "Every man loves a woman", given in (1) and (2).

(1) $\forall u.\mathsf{man}(u) \to (\exists v.\mathsf{woman}(v) \wedge \mathsf{love}(u,v))$
(2) $\exists v.\mathsf{woman}(v) \wedge (\forall u.\mathsf{man}(u) \to \mathsf{love}(u,v))$

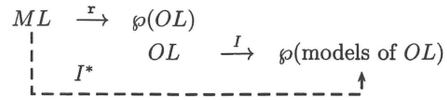
Informally, the description specifies the three "fragments" that must be put together to obtain a reading, plus constraints on the way they must be combined. The dotted lines can be thought of as "outscopes" relations; the same occurrence of the love subformula must be in the scope of both quantifiers. Because formulas have a tree-like structure in that each subformula is in the immediate scope of only one other formula, this means that the two quantifier fragments must take scope over each other. We will exploit this correspondence between formulas and trees in Section 4 to give the graph a formal meaning.

3 A Minimal Calculus of Direct Deduction

In this section, we present an abstract, general system of direct deduction. We first introduce a very flexible notion of underspecified entailment and then present a representative sample of the proof rules. For details, see [Jas99].

Entailment. Direct deduction is an operation on underspecified descriptions which is justified by the meanings of the described formulas. This means that any system of direct deduction must integrate two different systems: the resolution of underspecified descriptions to the readings they describe, and an inference system for reasoning on the object level.

Semantically, this means that an entailment notion for direct deduction must combine the reading enumeration function $\mathtt{r}$ that assigns to a description the set of its readings and the usual OL interpretation function I, roughly as in the following picture:



As the foundation of our calculus, we define a very flexible notion of underspecified entailment which combines the OL models with *partial disambiguation functions* (pdfs). A pdf $\mathtt{d}$ is a function which maps a ML-formula φ to a subset of the full set of readings described by φ, that is, $\mathtt{d}\varphi \subseteq \mathtt{r}\varphi$; and $\mathtt{d}\varphi = \emptyset$ iff $\mathtt{r}\varphi = \emptyset$. Intuitively, a pdf $\mathtt{d}$ represents a moment of interpretation at which certain readings described by φ are excluded, namely $\mathtt{r}\varphi - \mathtt{d}\varphi$.

An integrating interpretation I^* of an ML-formula φ is then obtained by combining OL-models with pdfs in the following way:

$$ML \xrightarrow{I^*} \wp(\text{models of } OL \times \text{pdfs})$$
$$I^*\varphi = \{\langle M, \mathtt{d}\rangle \mid M \in I\alpha \text{ for all } \alpha \in \mathtt{d}\varphi\}$$

In other words, φ is *true* at $\langle M, \mathtt{d}\rangle$ whenever all the readings described by φ that are not excluded by $\mathtt{d}$ are true at M. Entailment is then established in the standard fashion: $\varphi \models \varphi'$ iff $I^*\varphi \subseteq I^*\varphi'$.[1]

Direct deduction. A sound and complete calculus for this entailment notion can be obtained by extending a standard structural Gentzen calculus for the OL. The calculus consists of the following rules:

1. All the structural rules from the underlying calculus: reflexivity, transitivity, and monotonicity.[2]
2. The connective rules from the underlying calculus, lifted to unambiguous descriptions.
3. Two *total disambiguation* rules.

As an example for a connective rule, consider the standard rule $\underline{\wedge}R$, which introduces conjunctions on the right hand side of a sequent. Its counterpart in our calculus looks as follows (we say that φ is a unique description of the OL formula A if A is the only formula described by φ).

$$\varphi_1, \varphi_2 \vdash \varphi \qquad \begin{array}{l}\varphi_1, \varphi_2 \text{ unique descriptions of } A_1, A_2,\\ \varphi \text{ unique description of } A_1 \underline{\wedge} A_2.\end{array} \tag{3}$$

The total disambiguation rules look as follows:

$$\begin{array}{ll}\varphi_1, \ldots, \varphi_n \vdash \varphi & \varphi_1, \ldots, \varphi_n \text{ unique descriptions}\\ \varphi \vdash \varphi_1, \ldots, \varphi_n & \text{of the elements of } \mathtt{r}\varphi\end{array} \tag{4}$$

These sequents represent minimal disambiguation rules of which the first says that if (descriptions of) all the readings can be derived, then the ML formula describing this set can be derived as well. The second sequent says that from such a ML formula, the disjunction of its readings can be derived.

All the rules taken together form a calculus which is sound and complete for the pdf-semantics of ML [Jas97, Jas99].

[1] Earlier notions of underspecified entailment, which didn't allow partial disambiguation functions, led to notions of entailment that are either stronger or weaker than what is intuitively plausible [vD96]. The definition here is similar in spirit to a proposal in [Rey95] in that this entailment relation synchronizes partial disambiguation of condition and conclusion.

[2] In the case of 'realistic' linguistic inference, where pragmatic preferences come on stage, one may expect the loss of structural rules such as reflexivity [Pin99] and monotonicity on the ML-level.

Ambiguous descriptions. These rules are not very practical or efficient for direct deduction with dominance constraints since each disambiguation step requires full resolution, i.e., full specification of all the readings, of a ML formula. The calculus and semantics above can be tailored to allow stronger inference rules that can be used on descriptions with more than one reading.

The stronger variants of the total disambiguation rules (4) are the following *partial disambiguation rules*:

$$\varphi_1, \ldots, \varphi_n \vdash \varphi \quad \text{and} \quad \varphi \vdash \varphi_1, \ldots, \varphi_n \qquad \text{if } \bigcup_{i=1}^{n} \mathtt{r}\varphi_i = \mathtt{r}\varphi \tag{5}$$

Note that the applicability of this rule talks about the reading sets of the formulas appearing in the sequent, but this does *not* necessarily mean that it is needed to enumerate the readings to check applicability. We will illustrate an alternative in Section 5.

The two rules are unsound for the class of arbitrary pdfs. Soundness and completeness can be regained by restricting the class of admissible pdfs. The first rule corresponds to so-called *left monotonic* pdfs, whereas the second corresponds to *right monotonic* pdfs. A pdf $\mathtt{d}$ is left monotonic if whenever $\cup_{i=1}^{n} \mathtt{r}\varphi_i = \mathtt{r}\varphi$, there is an i such that $\mathtt{d}\varphi_i \subseteq \mathtt{d}\varphi$. A pdf $\mathtt{d}$ is right monotonic if under the same condition it holds that $\mathtt{d}\varphi \subseteq \cup_{i=1}^{n} \mathtt{d}\varphi_i$.

Similarly, connective rules can be generalized to apply to ambiguous descriptions too. For example, the conjunction rule (3) may be replaced by

$$\varphi_1, \varphi_2 \vdash \varphi \qquad \mathtt{r}\varphi = \{A \underline{\wedge} B \mid A \in \mathtt{r}\varphi_1, B \in \mathtt{r}\varphi_2\} \tag{6}$$

The corresponding restriction for the pdfs $\mathtt{d}$ is that $\mathtt{r}\varphi = \{A \underline{\wedge} B \mid A \in \mathtt{r}\varphi_1, B \in \mathtt{r}\varphi_2\}$ must imply $\mathtt{d}\varphi \subseteq \{A \underline{\wedge} B \mid A \in \mathtt{d}\varphi_1, B \in \mathtt{d}\varphi_2\}$. Generalizations for the other connective rules can be obtained in an analogous manner [Jas99].

4 Dominance Constraints

Now we present *dominance constraints*, a concrete formalism which has recently been proposed as a tool for semantic underspecification [ENRX98, KNT98]. Dominance constraints are a tree logic: a logic whose models are trees. It can be applied to natural-language semantics by considering OL formulas as trees and taking a dominance constraint φ to describe the formulas corresponding to the trees that satisfy φ. Trees are ground terms over a signature Σ of function symbols $f, g, \underline{\wedge}, \underline{\forall}, \mathsf{man}, \ldots$ with fixed arities.

The syntax of dominance constraints uses *node variables* $X, Y, \ldots$ and is defined as follows:

$$\varphi ::= X{:}f(X_1, \ldots, X_n) \mid X \triangleleft^* Y \mid \varphi \wedge \varphi'.$$

Dominance constraints are interpreted over trees τ and variable assignments α into the set of nodes of τ. A *labeling constraint* $X{:}f(X_1, \ldots, X_n)$ is satisfied by such a pair iff the node denoted by X is labeled with f and its children are denoted by $X_1, \ldots, X_n$. An *(atomic) dominance constraint* $X \triangleleft^* Y$ is satisfied iff X is mapped to a node which (reflexively, transitively) dominates the node denoted by Y. Logical connectives are interpreted in the usual way. For underspecified descriptions, we only use the (purely conjunctive) *constraint language*, but here we will also use the full first-order language, whose validity problem is decidable [KNT98].

We write equality $X{=}Y$ as an abbreviation for $X \triangleleft^* Y \wedge Y \triangleleft^* X$, $\mathcal{V}(\varphi)$ for the set of variables, and $\bar{\exists}\varphi$ for the existential closure of a dominance constraint φ.

A *constructive solution* of a dominance constraint φ is a pair (τ, α) that satisfies φ and has the property that every node in τ is denoted by a variable X for which a labeling constraint $X{:}f(\ldots)$ is in φ. Intuitively, constructive solutions don't contain "new material". In the first-order language, we can enforce constructivity of the models of a constraint φ by considering instead the models of the formula

$$\varphi^C \equiv \varphi \wedge \forall Z. \bigvee_{X:f(\ldots) \text{ in } \varphi} X{=}Z.$$

Dominance constraints describe their constructive solutions. So if we consider Fig. 1 as a graphical notation for a dominance constraint by reading the nodes as variables, the dotted lines as dominance constraints and the solid lines and labels as labeling constraints, the diagram gets a formal meaning as a dominance constraints describing exactly the two readings.

Finally, we can express that a constraint φ has *exactly one* constructive solution by requiring that

1. $\neg\bar{\exists}\varphi^C$ is not valid (that is, φ^C has at least one solution);
2. $\exists Y_1' \ldots \exists Y_n' \forall Y_1 \ldots \forall Y_n.(\varphi^C \rightarrow \bigwedge_{Y \in \mathcal{V}(\varphi)} Y{=}Y')$ is valid, where $\mathcal{V}(\varphi) = \{Y_1, \ldots, Y_n\}$, and $Y_1', \ldots, Y_n'$ are new variables.

The second condition expresses that there is at most one constructive solution. It literally says that there is only one possible variable assignment that satisfies φ^C. In a constructive solution, variable assignments are surjective, so this fixes the domain of a satisfying tree. Finally, each label is enforced by constructivity as well.

5 Direct Deduction with Dominance Constraints

Now we instantiate the abstract algorithm from Section 3 to the concrete underspecification formalism from Section 4. That is, we take the language of dominance constraints as the meta language ML; if φ is a dominance constraint, then, $\mathtt{r}\varphi$ is the set of constructive solutions of φ.

The abstract calculus in Section 3 consists of three different types of rules: structural rules, connective rules, and disambiguation rules. The structural rules are independent of the exact ML and OL, so we don't need to say anything about them here. Below, we encode the other two kinds of rules using validity problems of first-order dominance formulas.

To check the applicability condition of the more flexible conjunction rules (6), we must test (1) whether all constructive models of a constraint φ have the conjunction symbol $\underline{\wedge}$ as their root labels and (2) whether two other constraints, φ_1 and φ_2, are descriptions of the conjuncts. This is the case iff there is a variable $R \in \mathcal{V}(\varphi)$ such that

1. $\mathcal{V}(\varphi) = \mathcal{V}(\varphi_1) \uplus \mathcal{V}(\varphi_2) \uplus \{R\}$;
2. $\models \bar{\forall}\exists R_1 \exists R_2 (\varphi^C \leftrightarrow ({\varphi_1}^C \wedge {\varphi_2}^C \wedge R{:}\underline{\wedge}(R_1, R_2) \wedge \bigwedge_{Y \in \mathcal{V}(\varphi_i), i=1,2} R_i \triangleleft^* Y))$.

We get the original connective proof rules (3), which only work on non-ambiguous descriptions, by further requiring that both φ_1 and φ_2 only have a single constructive solution.

Of the two types of disambiguation rules, we consider the partial disambiguation rules (5) first. In order to test applicability of this rule, we must check whether the set of constructive solutions of a constraint φ is the same as the union of the sets of

constructive solutions of the constraints $\varphi_1, \ldots, \varphi_n$. This is the case iff the following validity holds:

$$\models \bar{\exists}\varphi^C \leftrightarrow \bigvee_i \bar{\exists}\varphi_i{}^C.$$

If we stick to the less powerful total disambiguation rules (4), we additionally require that each of the constraints $\varphi_1, \ldots, \varphi_n$ has a single constructive solution.

Validity of first-order dominance formulas is decidable, hence so are the applicability conditions of the proof rules. This means that we have defined a calculus for direct deduction with dominance constraints which is sound and complete with respect to the semantics defined in Section 3.

6 Conclusion

We have presented a sound and complete calculus for direct deduction with dominance constraints. It is an instantiation of the abstract calculus from [Jas99] and inherits its definition of underspecified entailment via partial disambiguations. The underspecification logic we have considered are tree descriptions with dominance constraints [ENRX98].

The proof rules require checking the validity of first-order formulas over dominance constraints, which is known to be decidable. But the complexity of these tests is non-elementary; furthermore, the proof rules can't be used to generate subformulas in proof search. So there is no straightforward way of building a theorem prover from this calculus.

This, of course, is an essential goal of future work. The most interesting aspect is probably to find versions of the partial disambiguation rules (5) that allow proof search. As it stands, all possible splittings of descriptions into more specific descriptions must be allowed to guarantee completeness. A more feasible version might obtain one specific partial disambiguation from a dominance constraint solver, building on previous work about disambiguation of dominance constraints, and still be complete.

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True to Fact(s)

Jacques Jayez, EHESS, Paris and Danièle Godard, CNRS and Université de Lille 3

1 Introduction

There is a long–standing controversy in the philosophy of language concerning the nature of facts. Linguists have used the term to categorize a type of semantic argument, introduced notably by factive predicates (*know*, *regret*, etc.). However, no clear definition of the category has emerged. The philosophical approaches oscillate between a realistic conception, where facts are akin to states of affairs in the world (Russell, Austin, Bennett) and a more abstract conception where facts are akin to informational entities (Strawson, Vendler, Devlin, Asher). In linguistics, it is unclear whether *fact* labels sentential arguments which can be paraphrased by *the fact that* S or arrays of distributional and semantic properties. The problem partly stems from a confusion between the lexical content of the word and the category of facts. In addition, as noted by Vendler (1967), *fact* and *facts* are semantically different, the plural noun being eventuality denoting. This difference is also observed in French. In this paper, we address the semantic and ontological status of the singular noun *fait* (*fact*) in French.

2 Distributional properties of *fait*

By using distributional data, Vendler was able to motivate an ontology distinguishing between different types of entities in the world. When applied to facts, the same methodology is less satisfactory. Vendler shows that facts are neither eventualities nor propositions, but does not offer a positive characterization. In particular, there is no single predicate or set of predicates which combines only with *fact*, in contrast with events, which are uniquely characterized by predicates such as *take place*.

We discuss three sets of properties which are taken to be crucial in the literature. First, *fait* can be the subject of *causer* ('cause'), as in *Le fait que Jean ait démissionné a causé de nombreux ennuis* ('The fact that John resigned caused a lot of trouble'). For Vendler, only facts can be the subject of 'cause'. Peterson (1997) argues that events also have this property and Asher (1993) considers that the causal efficacy of facts and events points to the existence of some connection between the two. Actually the 'cause' test is not discriminative at the distributional level, because there are few types of nouns which cannot be the subject of *causer*. Propositions can: *La proposition spinoziste que Dieu est la Nature a causé un énorme scandale dans certains milieux* ('Spinoza's proposition that God is Nature caused a deep shock in some quarters'). Objects in general are also acceptable (*This book caused some puzzlement*).

There is general agreement that facts lack spatio–temporal properties, which sets them apart from eventualities. This is true of *fait* in general, since it cannot be the subject of *avoir lieu* ('take place'), *durer* ('to last') and aspectual verbs or the complement of temporal prepositions. However, this widely accepted observation is too simplistic. *Fait* can be the argument of *se produire* ($\approx$ 'to happen'). It can also be the argument of adjectives like *nouveau* ('new'), *ancien* ('old'), *récent* ('recent'), *inopiné* ($\approx$ 'sudden'), which pertain to the temporal domain.

(1) a. Il s'est produit un fait intéressant ce matin.
lit. 'there happened an interesting fact this morning'
b. ??Après un fait aussi intéressant
'After such an interesting fact'

Finally, it is usually noted that, although the non–temporal properties of *fait* show it to be akin to informational objects, it cannot be the argument of 'true' and 'false'. Moreover, while *fait* is compatible with some adjectives appropriate for informational objects like 'theory' or 'idea' (*clair*, 'clear', *évident*, 'obvious',

irréfutable, ≈ 'indisputable', *douteux*, 'dubious', *avéré*, 'ascertained'), it cannot be a part of an informational object (*Cette idée/??Ce fait se trouve dans l'oeuvre de Spinoza*, 'This idea/This fact is found in Spinoza's works'). In this respect, *fait* is quite different from informational objects in general (Godard & Jayez 1994).

To sum up, while *fait* is neither an eventuality nor an informational object, it is not even clear that its distributional properties point to a stable category on a par with recognized lexical types (event, material object). One must account for this mixed behavior as well as for the combinatorial differences within each class of predicates.

3 Facts as Zalta–style abstract objets

We propose that *fait* refers to an *abstract object* (a.o.) in the sense of Zalta (1997, 1999). A.o. are sets of properties. Thus they evade spatio–temporal localization. There are several kinds of a.o.: fictional characters like Ulysses or Sherlock Holmes, Meinongian objects, numbers, propositional entities (for us, the entities which NPs like 'the proposition that' refer to), etc. We define the a.o. denoted by *fait* to be the set containing the property of warranting the truth of a certain proposition. For instance, the fact that Mary proved the theorem refers to a set containing the property of being such that the proposition 'Mary proved the theorem' is true. In addition, this a.o. is paired with the part of the world (event or state of affairs (s.o.a.)) which makes the proposition true. When this truthmaker is an event, predicates like *nouveau* can retrieve the event in the information structure associated with *fait*, whence the possibility of *nouveau fait* ('new fact').

The initial motivation for a.o. is philosophical. Elaborating on Meinong's and Mally's approaches Zalta aims at capturing the difference between an individual satisfying a property in the traditional, model–theoretic, sense and a property essentially characterizing an object. In the former case, the individual (an ordinary object) is said to *exemplify* the property, while the object (an abstract object) *encodes* the property in the latter case. For instance, John may happen to be a detective. In this case, he exemplifies the property of being a detective by accident. John may also be a detective in virtue of his nature (Fine 1995). He necessarily exemplifies the same property. Finally, John may be a fictional detective, like Sherlock Holmes, in which case he is a detective by stipulation and encodes (at least) that property.

(2) Let D be a domain of individuals, $a \in \mathbf{D}$, $\mathcal{P}$ a property and W a set of worlds. a satisfies $\mathcal{P}$ at some world $w \in W$ iff a is in the extension of $\mathcal{P}$ at w. Let A be a set of properties. A encodes $\mathcal{P}$ iff $\mathcal{P} \in A$.

Ordinary objects may exemplify spatio–temporal properties. In contrast, a.o. encode the property of being necessarily non spatio–temporal. Nevertheless, they appear to be the argument of predicates which involve space and time. For instance *Mary dreamt of Sherlock Holmes* refers to a particular eventuality. If a.o. are put in the same domain as ordinary objects, we lose well–foundedness. To avoid that, Zalta introduces special objets which are the proxies of a.o. in the domain of individuals. Proxies themselves are not spatio–temporal (they exemplify the property of being necessarily so), but they can enter spatio–temporal relations. In the above sentence, *Sherlock Holmes* denotes the proxy of the a.o. Sherlock Holmes.

Zalta's models have the form $\langle W, \mathbf{O}, \mathbf{S}, \mathbf{A} \rangle$, where W is the set of possible worlds, $\mathbf{O}$ the set of ordinary objects, $\mathbf{S}$ the set of special objects and A the set of abstract objects. For each relation R^n, $ext(R, w) \subseteq \{\mathbf{O} \cup \mathbf{S}\}^n$ is its extension at w. As indicated, $\mathbf{A}$ is the powerset of the set of properties. A function $\pi : \mathbf{A} \mapsto \mathbf{S}$ returns, for each a.o., its proxy in $\mathbf{S}$. Like a.o., entitites in $\mathbf{S}$ are not spatio–temporal but can exemplify relations with concrete entities. For instance, the logical form of Mary dreaming of Sherlock Holmes at a certain time t and location ℓ is:

Mary dreams of π(Sherlock Holmes) at $\langle t, \ell \rangle$

The connection between a.o. and proxies is given in (3).

(3) If an a.o. a encodes the property $\mathcal{P}$, its proxy $\pi(a)$ exemplifies $\mathcal{P}$ in every world.

Going back to the semantics of facts, we can now make sense of the divergent intuitions found in the literature. The distributional properties clearly show that an analysis of *fait* as denoting parts of the world is inappropriate. However, this analysis was based on the correct intuition that a fact is the *truthmaker* of a proposition. The symmetric option (a fact is proposition–like) is based on the intuition that a fact contains an information of the same type as a proposition. While it is clear that ordinary s.o.a. are truthmakers (Armstrong 1997), the idea that a.o. can also be truthmakers needs some explanation. Actually, a fact has the intrinsic property of being a truthmaker: it encodes the property of being such that a given proposition obtains. Similarly, there are abstract truthbearers, corresponding to *proposition*, *hypothesis*, *idea*, etc. An abstract truthbearer encodes the property of being such that there is some truthmaker which exemplifies 'being such that p or $\neg p$' for some p.

(4) An a.o. is a set of properties which contains the property $\lambda x.\Box(x$ is not spatio–temporal).
An a.o. is an abstract truthmaker iff it encodes the property $\lambda x.p$ for some p.
An a.o. is an abstract truthbearer iff it encodes the property $\lambda x.(\exists y.((\lambda z.p)\ [y] \vee (\lambda z.\neg p)\ [y]))$ for some p.

An analysis where an object can be both abstract and a truthmaker might seem counterintuitive. However, the linguistic data confirm that a fact is more difficult to reflect in the material world than propositions, a property which they share with ordinary truthmakers (events and s.o.a.). Minimally, propositions can be written (in a book or on a blackboard). This is not true for facts, as observed in section 2. Compare (5a) and (5b):

(5) a. Regardez la proposition que j'ai écrite au tableau et dites–moi si elle est correcte.
'Look at the proposition I wrote on the blackboard and tell me if it's correct'
b. ??Regardez le fait que j'ai écrit au tableau et dites–moi s'il est pertinent.
'Look at the fact I wrote on the blackboard and tell me if it's relevant'

Facts, like events and s.o.a., can be described, discussed, etc., but not physically coded since they have the function of things, not of informational entities. Only the latter can be physically coded. It has been proposed, in the framework of situation semantics, that facts are infons supported by actual situations (Devlin 1991, Ginzburg 1995). However, if facts were infons they should be amenable to some form of material coding. In addition, the relations and terms which are parts of infons should constitute parts of facts as well. But they do not. One may not refer to the 'arguments' or 'predicates' of a fact (*??Quel est l'individu mentionné dans le fait que vous venez de rappeler?*, 'Who is the person mentioned in the fact you just evoked?').

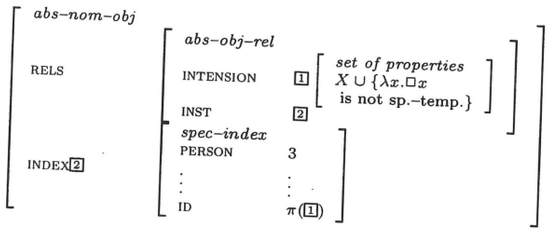
Like a.o. in general, facts have proxies, which allow them to be mentioned in episodic sentences ('Mary suddenly remembered a fact she had forgotten'). But facts differ from other a.o. in that they are also strongly connected with ordinary truthmakers, as stressed in (Bennett 1988, Asher 1993). Certainly, facts are not ordinary truthmakers, but they are paired with ordinary truthmakers which support a proposition. Let *tm* be an ordinary truthmaker which can be described by the proposition p. *tm* is part of the world and is the material truthmaker of p, or, in Zalta's terms, exemplifies the propositional property $\lambda x.p$. *tm* exists in itself, can be described by propositions, but is not defined as being the truthmaker of any proposition, in contrast with a fact. Consider f, the fact that p. f has a proxy $\pi(f)$

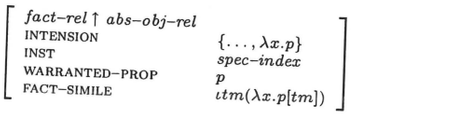
which necessarily exemplifies the property of being such that p, by definition (3). It is hardly conceivable that, in w, the proxy can warrant the truth of p without there being an ordinary truthmaker which warrants the truth of p. If it is a fact that Mary proved the theorem, there must be an event of Mary's proving the theorem. So, in every world w, $\pi(f)$ exemplifies $\lambda x.p$ iff, in w, there is a truthmaker tm such that tm (ordinarily) exemplifies $\lambda x.p$. In this respect, the proxy of a fact is strongly connected with the proposition $\exists tm((\lambda x.p)\ [tm])$. We call the ordinary truthmaker which satisfies this proposition in w the *fact–simile* of f in w. The connection with the fact–simile explains the temporal sensitivity of the word *fait*, noted in section 2.

This view of the relationship between facts, ordinary truthmakers (events or s.o.a.) and propositions bears a strong resemblance to that of Asher (1993). Roughly speaking, the proxy corresponds to the notion of 'event–type' and the 'companion proposition' corresponds to p in *the fact that p*. Our analysis differs from Asher's in at least two ways. First, the semantics of the word is not the same. In particular, we do not use the term 'abstract object' as a label, for a category similar to eventualities and objects. We exploit Zalta's analysis to shed light on the very notion of abstract object. This allows us to capture the fact that the relationship between a fact and its companion proposition is not the same than that between an event and the proposition which describes it. We show why the realistic dimension of facts (they are truthmakers) does not entail that they are in the world. Second, we propose that the link between a fact and its fact–simile is part of the lexical representation of the word.

4 Lexical representation

We represent the lexical content of *fait* using the feature–value format of HPSG (Pollard & Sag 1994, Copestake et al. 1997). Noun content is represented as a feature structure of type *nom–obj*. In order to accommodate a.o., we divide this type into the two subtypes *ord–nom–obj*, for nouns denoting an ordinary entity and *abs–nom–obj* for nouns denoting an a.o. A structure of type *abs–nom–obj* has the same two attributes RELS and INDEX as *ord–nom–obj*, but the values are different. RELS contains the predicative information of the N and an INST(ance) feature whose value is an index identified with the value of INDEX; the index points to an individual in the domain of interpretation. For *abs–obj–nom*, the type of the RELS value is *abs-obj-rel*, whose structure contains an attribute INTENSION in addition to the usual attribute INST. The value of INTENSION is a set of properties. It is characteristic of *abs–obj–rel* that the intension contains the property of necessarily being non spatio–temporal. The value of INDEX also is different from the standard value. In fact, we interpret the index as being that of the proxy, since only the proxy can be the argument of linguistic predicates. The index gets the new subtype *spec–index* with an additional attribute ID, which contains the proxy of the a.o. which is the value of INTENSION.





The lower structure represents the value of RELS in *fait*, which inherits from the type *abs–obj–rel*. The intension is a set of properties containing the property of being such that p. This reflects our analysis of *fait* as an abstract truthmaker. The type *fact–rel* has two special attributes: WARRANTED–PROP, which points to the proposition that the fact makes true and FACT–SIMILE, which points to the companion truthmaker of the fact. We assume that, in each world, there is a unique truthmaker which is the ordinary truthmaker of a given proposition p. It is widely accepted that reference is contextually restricted so that an episodic sentence is intended to point to a particular truthmaker. For generic sentences, which can express propositions warranted by facts (*le fait que les chats chassent les souris*, 'the fact that cats hunt mice'), the value of FACT–SIMILE should be the set of those hunting events whose participants are cats and mice.

It remains to account for the two distributional problems pointed out in section 2. First, how is it that *fait*, being an a.o., can be the argument of some temporal predicates and not others? The situation is even more complex because some predicates (*se produire*, 'to happen' and *inopiné*, ≈ 'sudden') but not others (*être témoin de*, ≈ 'to witness' and *nouveau*, 'new') are sensitive to the difference between *fait* and *le fait que*.

(6) a. Un fait intéressant s'est produit ce matin.
'An interesting fact happened this morning'
b. ??Le fait que le train a déraillé s'est produit hier soir.
'The fact that the train was derailed happened yesterday evening'
c. J'ai été témoin d'un fait intéressant ce matin.
'I (≈) witnessed an interesting fact this morning'
d. (?) J'ai été témoin du fait que le train a déraillé.
'I (≈) witnessed the fact that the train was derailed'

In recent work in lexical semantics, it is assumed that predicates can fetch information associated with the main type of a noun, as in *coercion* (Pustejovsky 1995) or *interpolation* (Godard & Jayez 1995). E.g., *a fast computer* can be analyzed as the modification by the predicate *fast* of the internal activity of the machine. Similarly, we propose that *se produire* and *être témoin de* can access the fact–simile present in the RELS of *fait*. Not every predicate has this ability. For instance *assister à* ('to attend') cannot take *fait* as complement, because it requires it to be of type event. *Être témoin de* is less constrained: (i) it selects events or s.o.a. as semantic arguments; (ii) it can combine with *fait* because it accesses the FACT–SIMILE attribute in *fait*. Note that there are certain events which are indirectly associated with nouns.[1]

Unlike *être témoin de*, *se produire* accepts *un fait* but not *ce/le fait (que)*. We propose that verbs which select an event (not an s.o.a.), e.g. *attendre* ('to wait'), do not combine with *ce/le fait (que)*. In our analysis, the fact–simile of *fait* is an ordinary truthmaker, either an event or an s.o.a. The exact type of the truthmaker (event vs s.o.a.) is fixed by the determiner. With the indefinite, the truthmaker is underspecified while it must an s.o.a. with the definite. *Se produire* and *attendre* take events. *Être témoin de* takes events or s.o.a. provided that they are supported by events that one can observe.[2] In this way, we keep the semantics compositional while accounting for the observed contrasts.

[1] *Être témoin de* does not simply look for a metonymic associate of the noun, but requires it to be part of the RELS value. The word *book* is associated with a reading event (Pustejovsky 1995). However, it is not possible to 'witness' a book because the reading event is not part of the RELS value.

[2] So it is possible to (lit.) 'witness an atmosphere' (*J'ai été témoin de cette mauvaise ambiance*, 'I (lit.) witnessed this bad atmosphere'), but not to witness a state without any specific manifestation (*?? J'ai été témoin de sa présidence*, 'I (lit.) witnessed his presidence', *?? J'ai été témoin du fait que 2 et 2 font 4*, 'I (lit.) witnessed the fact that 2 plus 2 is 4').

Turning to the second problem, we must explain why a fact cannot be true or false, while it can be dubious, ascertained or irrefutable. This list of predicates is sufficient to eliminate the hypothesis that truth predicates are redundant or contradictory (Vendler 1967). If facts were strongly factual, a dubious fact would be as contradictory as a false fact. The factuality of facts is limited to the impossibility for an agent to deny a fact that he assumes in the current information state. We assume that the different modal perspectives (common ground, hypothetical or counterfactual information) correspond to different sets of worlds (information states, Veltman–style). This allows us to retain definition (3) by relativizing it to a particular set of worlds. As to the differences between lexical items, they are explained along the same lines as in the previous case. Some truth predicates require that the type of the RELS value be that of a truthbearer, which *fact–rel* is not. Others are able to retrieve the proposition warranted by the fact.

5 Conclusion

As the denotation of the noun *fait*, a fact is a tough thing. Two factors explain the difficulty with estimating the position of facts on the semantic map. First, as demonstrated above, facts are neither states of affairs nor descriptions of them. They are intensional objects (abstract truthmakers) which cannot be analyzed in the standard way of modern metaphysics. Second, predicates may select facets of the noun rather than its main semantic type. This makes a purely distributional analysis virtually impossible, or at least rather inefficient in some cases. This suggests that *fait* does not correspond to a distributional type but rather to a referential one. *Fait* does not point to a class of distributions, in contrast with event nouns for instance, but to a certain kind of conceptual entity associated with auxiliary entities ('companions') themselves possessing a distributional type.

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Semantic Composition for Partial Proof Trees

Aravind K. Joshi (1), Seth Kulick (1), Natasha Kurtonina (2)
(1)Institute for Research in Cognitive Science, University of Pennsylvania, USA
(2)Fitchburg State College, Fitchburg, Massachusetts, USA

Summary: We address the problem of semantic composition in a categorial system based on a hybrid logic. One logic is used for unfolding a categorial type, resulting in a partial derivation. The second logic computes the semantic representation from those partial derivations. We encode the history of the derivation from the first logic by using bound variables to represent the missing assumptions. Since the application of the partial derivations can take place in either direction in the second logic, this allows for a semantic representation with λ-terms embedded inside λ-terms. We show that by allowing such terms to be moved to the outermost position, compositionality can be maintained in the hybrid logic.

There has recently been work by various authors (e.g, [2, 3, 5]) suggesting that a categorial grammar derivation can be reconceptualized by using a hybrid logic. One logic is used for unfolding a categorial type, resulting in what might be considered a partial derivation or a proof-net, depending on one's preference. A second logic is used to combine these items, which are now "larger" than the usual categorial types, to form the final derivation. It has been argued in [3] that if the use of structural modalities is limited to the first logic, then this has several advantages in terms of the enforced localization of the use of structural modalities to the (small) domain of these partial proofs. Furthermore, since structural modalities are so localized, this in effect means that any analogs of transformations or movement must take place within these partial proofs. Therefore, semantic composition for the derivation must take these pieces of semantic representation in which these movements are already encoded - in a sense, "offline", by the first logic - and compose these larger units. This is therefore a return to some of the early ideas of combining transformational grammar and Montague grammar, such as that of [1], in which the derivational history is used to compute the semantics, but each step of the derivational history is larger than a single type, and can include clausal transformations.

However, what has been missing from much of this work is a precise account of how the semantic correspondence of the first logic is represented, and how the second logic computes using these representations. In this paper we address several issues related to the semantic compo-

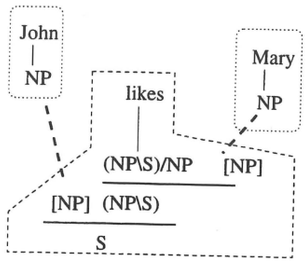

Figure 1: Partial Proof Trees for *John, likes, Mary*

sition of such a hybrid logic in the context of the system discussed by [2, 3].

Figure 1 illustrates a a simple case, for the sentence *John likes Mary*. The verb is unfolded into a partial proof with two unfilled assumptions, for the two NPs. Semantically, this can of course be seen as the usual lambda term (1).

(1) $\lambda obj.(\lambda subj.\ (\mathbf{like}'\ subj\ obj))$

Each of the NPs is linked to the partial proof for *likes* by cut on the partial proofs, and semantically this corresponds the use of function application. However, due to the unfolding of the syntactic type, both NP arguments are "equally available", and application in either direction can take place first. The main issue is therefore how to allow the derivation from either direction, thus allowing it to take the subject or object argument first. The use of two logics incorporated in a hybrid logic allows us to take a different approach than the standard one of using associativity to rebracket the types, as in Lambek categorial systems, or an explicit rule of function composition, as in Combinatory Categorial Grammar ([8]).

To allow the derivation from either direction, we use associativity on proofs, not the individual types - i.e., we have associativity *only* in the logic to combine the proofs, not in the logic to create the proof trees. Several consequences from this. First, we do not have, nor need, rebracketing of strings. Second, even though we have full associativity in the second logic, it does not increase complexity of derivation. We still have polynomial parsing, in contrast to associative categorial grammar in which the question is still open. This point can be generalized, in that the use of a hybrid logic lessens and localizes the need for structural modalities, which increase the complexity problem even further.

The third point, and for this paper the crucial one, concerns the composition of a semantic representation in such a system. We fol-

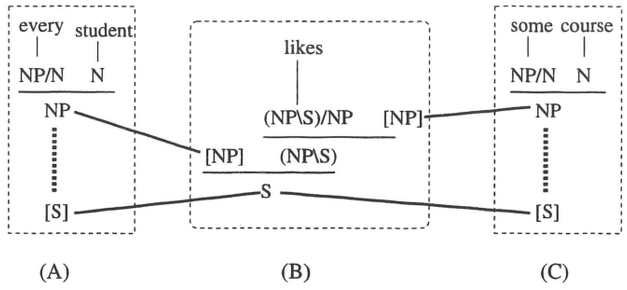

Figure 2: Partial Proof Trees

low the standard categorial view that the semantic representation is computed simultaneously with the syntactic derivation. The crucial difference here is that the units composed during the derivation are larger than single types, thus encoding partial histories of the derivation. We do not use a normal form with all the lambdas at the top. Instead, the lambdas are placed at the point where they are actually used. This allows us to easily keep track of where the assumptions are actually needed in relation to the verb. In a simple example like the previous one this difference cannot be seen, but it becomes apparent in a more complex example, as in the handling of the classic case of quantifier ambiguity in (2).

(2) Every student likes some course

In recent work [4] suggest in this PPT system that this can be handled by the use of "interpolation" in the unfolding of the *every* and *some* trees, so that in addition to taking an N argument, the proof has a "gap" in it from NP to S, thus being a structural analog of type-raising for a generalized quantifier, as shown in Figure 2. Intuitively, this is a request for a proof tree which has NP as an undischarged assumption and S as a conclusion.

Each PPT is associated with a semantic representation. Assuming for simplicity that the determiners and nouns have combined, we thus have the following three semantic representations for the three partial proof trees:

(3) $\lambda p.(\forall v.(\mathbf{student}'\ v \rightarrow (p\ v)))$
(4) $\lambda obj.(\lambda subj.\ (\mathbf{like}'\ subj\ obj))$
(5) $\lambda p.(\exists u.(\mathbf{course}'\ u \wedge (p\ u)))$

To derive either scope reading, the derivation must be able to proceed from either direction. We discuss first the wider scope for *every* over *some*. This requires first combining (B) and (C) in Figure 2. The

resulting tree will still have a remaining NP assumption (for the subject) and S conclusion, and so can then be combined with Tree (A).

The semantic derivation analog is that (5) combines with (4) first, with the result combining with (3), so that *every student* will take scope over *some course*. Applying (5) to (4) by lambda application gives the result in (6). Note that a lambda term is embedded within (6). This is the semantic corollary of unfolding the types. For the final step of the derivation, (6) is transformed into (7), with the bound variable now at the top. This is the semantic corollary of having associativity in the second logic, the logic of combining the PPTs. The final step follows by (3) applying to (7), resulting in the required reading (8) with wide scope for *every student*.

(6) $\exists u.(\mathbf{course}'\ u \wedge (\lambda subj.\ (\mathbf{like}'\ subj\ u)))$
(7) $\lambda subj.(\exists u.(\mathbf{course}'\ u \wedge (\mathbf{like}'\ subj\ u)))$
(8) $\forall v.(\mathbf{student}'\ v \wedge (\exists u.(\mathbf{course}'\ u \wedge (\mathbf{like}'\ v\ u))))$

The derivation for the other scope reading is done in a parallel manner, by first combining (A) and (B), again resulting in a tree with an unfilled NP assumption and conclusion S, and which therefore can be combined with (C). The semantic derivation works as described for the previous case, with the additional first step of moving the second bound variable (*subj*) in (4) to the outermost position, since (3) expects as an argument λ-term abstracting over the subject.

In both cases, we maintain the structure of the partial proofs by allowing the bound variables to be located within the λ-terms. Since there are no abstractions dependent on other abstractions, this is guaranteed not to cause a problem. We have implemented a prototype version of this approach by encoding the terms in "higher-order abstract syntax" ([6, 7]) , using the logic programming language λProlog as a meta-language to encode the object-level semantic descriptions. Using the ability of this language to manipulate bound variables and lambda terms allows for a clean implementation of the abstraction of a bound variable to the outermost position.

In conclusion, the use of a hybrid logic has a number of consequences from both the semantic and syntactic perspectives. The derivational history is used for semantic computation. The objects used for the semantic composition are larger than a single type, and therefore each encode a partial history of the derivation. This allows for a different approach to issues of the syntactic/semantic interface.

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A proof-theoretic view of intensionality

Reinhard Kahle
WSI — Universität Tübingen

Abstract

We discuss a proof-theoretic view of intensionality. Based on a notion of the *use* of a formula in a proof we show how a proof-theoretic account can avoid some well-known difficulties of the representation of intensional phenomena. The key example is binary necessity, where we read *"A is necessary for B."* as *"Every proof of B uses A."* Provided that A is an axiom or an atomic proposition we can give a formalized version of this reading. This theory is compared with the standard modal logic approach to necessity and two examples are given. Finally we give an outlook over further applications of the proof-theoretic view of intensionality which turn out to be a nice example of interdisciplinarity between logic, philosophy, linguistics and computer science.

1 Introduction

Intensional phenomena arise in many different contexts. The following list gives some examples from the fields of philosophical logic, linguistics and computer science:

- Necessity
- Counterfactuals
- Knowledge representation
- Beliefs / Belief revision
- Database update

The common feature of these frameworks is the lack of closure under logical equivalence. In fact, this characterization can be used as a definition of the notion of *intensionality*.

From this point of view, the problem with classical set theoretic semantics is obvious: By definition set theoretic semantics is closed under logical equivalence. A way out of this dilemma was shown by Kripke's famous *possible world semantics* which has been successfully established as the standard semantics for intensionality [4]. Nevertheless, there are still problems. For instance, every tautology is valid in every possible world. If we think of beliefs, it is quite doubtful whether an agent really believes every tautology independently of its complexity.

Even for necessity it follows that all tautologies are necessary for every other proposition. This is adequate with respect to *logical necessity*, but in no way with respect to *epistemic necessity* or necessity as it is used in natural languages.

We will propose a new view of intensionality by means of proof-theoretic notions. With respect to necessity the rough idea can be described as follows. Consider necessity as a binary relation. We read

$$A \text{ is necessary for } B.$$

as

$$\text{Every proof of } B \text{ uses } A.$$

This reading requires two explanations: First we have to say something about the domain of the proofs — in contexts which are not formalized we can speak of

arguments instead. Secondly the notion of *use* has to be investigated. But already at this stage it should be obvious that some problems are ruled out by the naive notion of use: For surely not every tautology is used in a proof of a proposition and consequently not every tautology is necessary for every other proposition.

Instead of giving an abstract theory, here we concentrate on two examples illustrating our approach for the case of necessity. (A more technical approach can be found in the technical report [2].) The first example is taken from mathematics. Here we have the advantage that the formal framework is clear defined. The second is a much more "real life" example. We will discuss necessity statements about forthcoming soccer matches. In the final section we give an outlook how our approach could be used for other intensional phenomena.

2 A "formal" example

Usually mathematicians accept ZFC, the well-known Zermelo-Fraenkel set theory with the axiom of choice, as the appropriate formal framework for mathematics. Nevertheless, during the so-called "Grundlagenkrise" of mathematics the axiom of choice was attacked by some mathematicians, first of all by Brouwer, because of its missing constructiveness. Even if nowadays the dispute between intuitionists and so-called classical mathematicians is ended (not necessarily solved) working mathematicians stress as a rule the use of the axiom of choice in proofs of theorems. Moreover, it is particularly mentioned if the axiom of choice is really *necessary* for a certain theorem.

In mathematics we have the well defined notion of *necessary condition*, saying that A is a necessary condition for B iff B implies A. Nevertheless, we claim that in the statement

The axiom of choice is necessary for Hilbert's Basis Theorem. (1)

"is necessary" does not mean "is a necessary condition" (even if it is true that it is a necessary condition). By definition, all tautologies are necessary conditions for every other statement. But statements like

"A implies A" is necessary for Hilbert's Basis Theorem.

does not match with the use of necessity in the meta-mathematical language (and here we discuss meta-mathematical statements). Based on a notion of "use" our reading of (1) is

Every proof of Hilbert's Basis Theorem uses the axiom of choice. (2)

This examples allows to discuss several aspects, in particular the two questions mentioned in the introduction: The domain of the quantifier over proofs and the notion of "use".

First of all we avoid pathological cases by demanding that the consequence of a necessity statement should be a provable formula (otherwise there would be no proof at all). We will come back to this problem in the next section.

If we are interested in a *subjective* notion of necessity, either with respect to a community or with to respect of a certain person P we can read (2) as

Every *known* proof of Hilbert's Basis Theorem uses the axiom of choice.

or

Every proof *known by* P of Hilbert's Basis Theorem uses the axiom of choice.

Such a reading is of particular interest for the use of necessity in natural language, see below. Nevertheless that we cannot have an actual access to *all* proofs of Hilbert's Basis Theorem, in a formal framework we are able to prove the following statement

Every proof of Hilbert's Basis Theorem *has to* use the axiom of choice.

by its contraposition (so we do not run in a circular argument)

There is no proof of Hilbert's Basis Theorem which does not use the axiom of choice.

Such non-existing proof can be given by counterexamples, for instance by construct a model of ZF (without the axiom of choice) in which Hilbert's Basis Theorem is false.

This leads to the second question, the notion of *use*. It is far from obvious how to define this notion precisely. Even in mathematics there are different way to define the formal framework, for example as a Hilbert-style calculus, a Gentzen-style sequent calculus or in natural deduction-style. For Hilbert-style calculi we can say a formal is used in a proof if it occurs as on a single line. But an adequate definition should by invariant under the change of the calculus. Since it is quite unclear what happens with a formula which is used in Hilbert-style proof (in the sense above) after a translation in natural deduction we restricted ourselves to an unproblematic case here. The use of an *axiom* is easy to define:

An axiom A of an axiom system T is used in proof of B, if B is unprovable in T' where T' is T without A.

As indicated above such unprovability statements can be shown by given a counter model.

In fact, our approach make use of the dualism of proof theory and model theory: "There *exists* a proof of A" corresponds to "A is valid in *all* models." So existential quantification over proofs corresponds to universal quantification over models and the other way around. While we need model theoretic arguments to prove necessity statements (in the rigid, non-subjective sense), non-necessity statements are proved by purely proof-theoretic notions.

A is not necessary for B.

can be easily shown (and we claim that this is the standard way how it is usually done) by giving a proof of B which does not use A.

As a last argument for our reading of necessity let us consider a statement like

Some version of the axiom of choice is necessary for the Theorem T.

In this case the implicative reading "T implies some version of the axiom of choice." is rather strange. But the proof-theoretic reading "Every (known) proof of T uses some version of the axiom of choice." seems to be quite natural.

To sum up we have:

- If A is an axiom and B a provable formula, statements of the form

  A is necessary for B.

  can be read as

  Every proof of B uses A.

- For a subjective notion of necessity the quantifier over proofs can be restricted by saying

  Every *known* proof of B uses A.

- The use of an axiom in all proofs can be shown by model theoretic means.
- Negative necessity statements

  A is not necessary for B.

  by giving a counter example, a proof of B which does not use A.

3 A "real life" example

To investigate examples of necessity statements from natural language, we consider a league table of four soccer teams after the last but one round:

Team	Points
A	4
B	4
C	3
D	0

In the last round A has to play D and B has to play C.

In this context, we will analyze the following two necessity statements:

C beats B is necessary for C to win the league. (a)

C beats B is necessary for C to reach the second place. (b)

As above we propose to read (a) and (b) as

Every proof of "C wins the league" uses "C beats B".

Every proof of "C reaches the second place" uses "C beats B".

This reading requires first of all a formal framework so that we can speak about proofs or, more appropriate in this context, about arguments. But this is more or less straightforward. Such a framework can build from the rules of soccer: A team gets three points of a win, one for a draw, the table are sorted first by points than by goal difference, and so on. Moreover we have to add the results of the matches already played as further axioms of the actual state of the situation. The general laws and the fixed results form the *background premises*. The concept of background premises is well-known from the modal logic approach to intensionality, where they are used to determine the variety of possible worlds, cf. [3, 5]. Maybe the only difference is that we really need an axiomatic representation of the background premises for our approach.

Now we face the problem mentioned above: Even if we have a formal framework of the situation described above, obviously, there is no proof at all that C wins the league. For this reason we have to extend our approach to *potential proofs*. Informally a potential proof is proof which can use the background premises and additional *potential axioms*. In our example the potential axioms should be obvious: The possible results of the remaining matches. The formal definition of potential proofs would need more effort, in particular we have to ensure several constraints. The most trivial constraint is that we cannot use two different potential axioms which excludes themselves, like "A beats D" and "A draws D". Nevertheless the informal notion should be clear. So we refine our definition of necessity statements

A is necessary for B.

by

Every *potential* proof of B uses A.

Now it is easy to check that every argument for the fact that C will win the league (according to the rules of soccer) will use the "axiom" that C beats B.

Analogously we can falsify statement (b) just by giving an argument how C can reach the second place without beating B. In fact, if they draw and A looses against D with an appropriate high goal difference, C will be second.

In particular the first example shows an essential feature of the proof-theoretic reading compared with usual modal logic ones: Obviously the argument for the necessity statement does not depend on the result of the match between A and D. The modal logic reading yield "In every possible world in which C wins the league, C beats B". But to speak about a *world* W means that we have to know all true statements W, i.e. even the result of A against D (which, of course, will differ in different worlds). Our approach yields immediately the irrelevance of the match A against D. In contrast for the rejection of (b) the match of A against D is relevant, because it has to use in the proof which falsify the statement. (For a strong reading of "relevance" one would have to show that it has to use in *all* proofs which falsify the statement, what is indeed the case). So here we see already how our approach can also be used to study *relevance*.

We will close this section by notice the following fact: By ignoring our intuition for "use" we can read "A is used in a proof of B" as "A is valid in all possible worlds in which B is valid". In this case, it turns out that our reading of necessity coincides exactly with the usual modal logic one. For this reason, the latter one (which is indeed the adequate formalization of *logical necessity*) can be regarded as limit case of our approach. In general, we like to make use of the additional structure which is provided by a (or all) proof(s) of A in contrast to the sheer truth (conditions) of A.

4 Outlook

In the last section we already gave a hint how our approach is related to *relevance*. As for necessity, here we consider binary relevance, i.e. the question whether a A is relevant for B. The usual approaches to relevance are much more concentrate of the relevance as a property of a derivation system, not as a relation between two sentences, cf. [1].

Of course, one of the most interesting topics for intensionality are *counterfactuals*. Here we will just illustrate the road on which counterfactuals can be handled from a proof-theoretic point of view (even if such a theory is not worked out yet). Let us assume that we can describe certain situations terms of axioms, like for the soccer example. Moreover we restrict ourselves to the case that we study counterfactuals which question axioms only, like a particular result of a match, say A was beating B. In this case we have careful ban the use of "A was beating B" from further arguments, but allow to use the new assumption, say "A was drawing B". Such an approach requires a lot of effort, in particular we would need a rigid concept of independence of axioms. Nevertheless, we do not need such vague concepts like *comparative similarity* [5, p. 1]. On contrast, we have hope to work an analysis of counterfactuals based on the notion of *use*.

In the same way, *knowledge representation* and *belief revision* seems to be topics where a proof-theoretic representation allows a deeper analysis. Let us think of the classical definition of knowledge as true and justified belief. One method of check the justification of a belief A is just the question "Why do you belief A?" As an

answer we expect an argument — not a truth value! And if the argument contains serious logical mistakes, we would reject that somebody is knowing A even if A is true.

Let us finish with a remark about the more formal aspects of our approach. Of course, the notion of use is slightly vague with respect to natural language. In the same way natural language is for sure not a formal framework. But if we think of computer languages we will find both: A formal framework and a precise notion of use. At least for the propositional part our approach can directly applied to *logic programming* where the use of a fact in a resolution tree can easily be checked. On step further, *deductive databases* are conceptional nothing else than logic programs. So the proof-theoretic account has also potential application in database update. Similarly we can look at the functional side of computer science. On the basis of the the famous Curry-Howard isomorphism proofs and functions are closely related. But in computer science, functions are intensional objects. The intensional view of functions and its application to intensionality in general is elaborated by Moschovakis on the basis of recursion theory, cf. [6]. One aim of our approach is to make use of this well-established intensional view also for our proof-theoretic considerations in general. So the proof-theoretic account gives rise to a broad interdisciplinary cooperation of logic, philosophy, linguistics and computer science.

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Factoring Predicate Argument and Scope Semantics: Underspecified Semantics with LTAG*

Laura Kallmeyer
University of Tübingen

Aravind Joshi
University of Pennsylvania

Abstract

This paper proposes a compositional semantics for lexicalized tree-adjoining grammar (LTAG). Tree-local multicomponent derivations allow separation of the semantic contribution of a lexical item into one component contributing to the predicate argument structure and a second component contributing to scope semantics. Based on this idea a syntax-semantics interface is presented where the compositional semantics depends only on the derivation structure. It is shown that the derivation structure (and indirectly the locality of derivations) allows an appropriate amount of underspecification. This is illustrated by investigating underspecified representations for quantifier scope ambiguitites and related phenomena such as adjunct scope and island constraints.

1 Introduction: Multicomponent LTAG

A LTAG consists of a finite set of trees (elementary trees) associated with lexical items and composition operations of substitution (replacing a leaf with a new tree) and adjoining (replacing an internal node with a new tree). The elementary trees represent extended projections of lexical items and encapsulate syntactic/semantic arguments of the lexical anchor. They are minimal in the sense that all and only the syntactic/semantic arguments are encapsulated and further, all recursion is factored away. This factoring of recursion is what leads to the trees being extended projections. The elementary trees of LTAG are therefore said to possess an extended domain of locality.

In our approach we use a LTAG varient called multicomponent TAG (MC-TAG). A MC-TAG consists of elementary sets of trees. The locality of composition in LTAG is extended to MC-TAG as follows. Basically, when two multicomponent tree sets are combined, the components of one set combine with only one of the components of the other set. This formalism, called tree-local MC-TAG, is known to be equivalent to LTAG, thus the use of MC-TAG does not take us beyond the power of LTAG. We use tree-local MC-TAG with at most two components in each set. The key idea is that one of the components of a tree set contributes to the predicate argument aspects of semantics and the other component contributes to the scope semantics. This allows us to obtain derivation trees that provide the right kind of underspecification for scope semantics.

2 Derivation trees and semantic dependencies

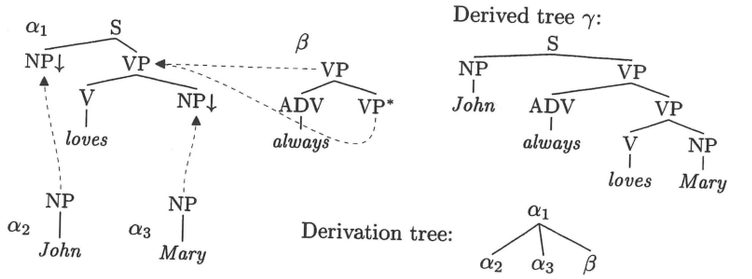
LTAG derivations are represented by derivation trees that record the history of how the elementary trees are put together. A derived tree is the result of carrying out the substitutions and adjoinings.

(1) John always loves Mary.

*This work was done during a visit of Laura Kallmeyer at the Institute for Research in Cognitive Science (IRCS), University of Pennsylvania. A longer version of the paper will appear as technical report at IRCS.

The elementary trees for (1) are shown in (2) together with the derived tree γ and the derivation tree. γ is generated by adding α_2 and α_3 by substitution in α_1 and adjoining β to α_1. This is reflected by the derivation tree: An edge to an intitial tree $\alpha, \alpha_1, \ldots$ stands for a substitution and an edge to an auxiliary tree $\beta, \beta_1, \ldots$ for an adjunction.

(2)



Because of the localization of the arguments of a lexical item within elementary trees the proper way to define compositional semantics for LTAG is with respect to the derivation tree rather than the derived tree. We assume that each elementary tree is related to a semantic representation. The derivation tree indicates how to combine the semantic representations, where the direction of a semantic composition depends on the specific syntactic operation: In case of a substitution an argument is added to the semantic representation, and when adjoining a tree the new semantic representation is applied to the old one. This contrasts with traditional approaches where each node in the syntactic structure is associated with a semantic representation. Although this insight has been present from the beginning of the work on LTAG (Shieber & Schabes 1990) a systematic formulation was begun only recently by Joshi and Vijay-Shanker (1999). One of their goals was to investigate the role of underspecification in compositional semantics; they suggested that LTAG derivation trees provide just the right amount of underspecification necessary for scope semantics. Their discussion was preliminary, however.

(3)

σ_{α_1}	σ_{α_2}	σ_{α_3}	σ_{β}
$l_1 : loves(x_1, x_2)$	$john(x)$	$mary(y)$	$l_2 : always(s_1)$
arg: x_1, x_2	arg: –	arg: –	arg: s_1

(3) shows the semantic representations linked to the elementary trees in (2). We use 'flat' semantic representations (as in, for example, Minimal Recursion Semantics MRS, Copestake et al. 1997) consisting of a conjunctively interpreted set of formulas (typed lambda-expressions) and a set of argument variables. The formulas may have propositional labels $l_1, l_2, \ldots$. Roughly, the application of one semantic representation σ to another σ' consists of assigning values (of appropriate type) from σ' to some of the arguments in σ and then building the union of σ and σ'. In (3), σ_{α_1} is applied to σ_{α_2} assigning x to x_1 and to σ_{α_3} assigning y to x_2. σ_β is applied to σ_{α_1} with l_1 assigned to s_1. The result is (4):

(4)

$l_1 : loves(x, y),\ john(x),\ mary(y),\ l_2 : always(l_1)$
arg: –

3 Scope information and underspecification

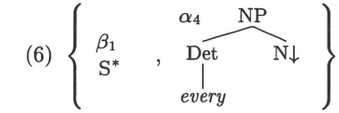
In order to describe underspecified representations for scope ambiguities, we adopt ideas from Hole Semantics (Bos 1995) and enrich the semantic representations with

propositional metavariables $h_1, h_2, \ldots$ called holes. A partial order on holes and propositional labels describes the scope structure of a semantic representation. A disambiguation function maps holes to propositional labels in such a way that the scope constraints are respected.

(5) Every student loves some course.

Consider (5) for example. We suppose scope components of quantifiers to be syntactically empty, they are auxiliary trees containing one single node. (6) shows the elementary tree set for *every*, together with the derivation tree for adding this quantifier to *loves*.

(6)



(7)

σ_{α_1}	σ_{β_1}	σ_{α_4}
$l_1 : loves(x_1, x_2)$	$l_2 : every(x, h_2, h_3)$	$l_3 : p_1(x)$
$l_1 \leq h_1$	$s_1 \leq h_3$	$l_3 \leq h_2$
arg: x_1, x_2	arg: s_1	arg: p_1

(7) shows the (revised) semantic representations of α_1 from (2), β_1 and α_4. The constraints $s_1 \leq h_3$ and $l_3 \leq h_2$ in σ_{β_1} and σ_{α_4} separate restriction and body of *every*. The auxiliary tree in the tree set of a quantifier contributes to scope semantics: it introduces slots (h_2 and h_3 in the case of *every*) for the scope of the quantifier, i.e. its restriction and body. The NP part of the tree set contributes to the predicate-argument semantics: it is inserted as a syntactic argument and it contributes (a part of) the restriction of the quantifier. The argument p_1 in σ_{α_4} stands for the predicate denoted by the noun in the NP that will be added by substitution. This separation between scope information and contribution to the predicate argument structure is partly inspired by Muskens (1998) and Muskens & Krahmer (1998).

To make sure that in a substitution step the corresponding argument variables are chosen in the semantic representation, each substitution node is linked to at least one argument variable. In (7) the subject NP of α_1 is linked to x_1 and the object NP to x_2. The N substitution node in α_4 is linked to p_1.

The derivation tree in (6) indicates that σ_{β_1} is applied to σ_{α_1} assigning l_1 to s_1, and σ_{α_1} is applied to σ_{α_4} assigning x to x_1. This leads to (8):

(8)

$l_1 : loves(x, x_2),\ l_2 : every(x, h_2, h_3),\ l_3 : p_1(x)$
$l_1 \leq h_1,\ l_1 \leq h_3,\ l_3 \leq h_2$
arg: x_2, p_1

Similarly, semantic representations for *some* are added, where the scope component is also adjoined to the root of α_1. Adding then *student* and *course* gives (9):

(9)

$l_2 : every(x, h_2, h_3),\ l_4 : some(y, h_4, h_5),$ $l_1 : loves(x, y),\ l_3 : student(x),\ l_5 : course(y)$ $l_3 \leq h_2, l_1 \leq h_3, l_5 \leq h_4, l_1 \leq h_5,\ l_1 \leq h_1$
arg: –

With the constraints in (9), $loves(x, y)$ is in the scope of both quantifiers, $student(x)$ in the scope of *every* and $course(y)$ in the scope of *some*. The scope relation between *every* and *some* is unspecified. Thus this approach generates underspecified representations for scope ambiguities.

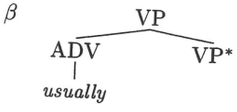
Since LTAG parsing is polynomial it follows that the construction of the underspecified representaion in the derivation tree is also computable in polynomial time.

4 Adjunct Scope

(10) Pat allegedly usually drives a cadillac.

(10) is an example of adjunct scope taken from Bouma et al. 1998. As pointed out by Bouma et al., in (10) *usually* must be in the scope of *allegedly*. Considering only cases where both adverbs are VP-modifiers, there are three scope orders: *allegedly* must have scope over *usually*, and the quantifier *a cadillac* can either have wide scope or be between the two adverbs or it can have narrow scope.
(11) is a natural elementary representation for VP-modifiers as *usually*:

(11)



$l_1 : usually(h_1)$
$s \leq h_1$
arg: s

Schabes & Shieber (1994) would argue that in (10), both adverbs are adjoined to the VP-node of *drives*, i.e. they would prefer multiple adjunction in this case. They propose to consider the scope constraints for (10) as a consequence of the specific syntactic derivation order. However, one of our underlying assumptions was that the compositional semantics depends only on the derivation tree. In particular, it should be independent from syntactic derivation order. Therefore, contrary to Schabes & Shieber, we assume that for tree sets containing single auxiliary trees, multiple adjunctions of several such trees at one and the same node are not allowed. The difference between adverbs modifying the whole VP and adverbs modifying only an embedded adverb is accounted for by adjoining in the first case at the VP-node and in the second case at the node with label ADV (with a different semantic representation). The restriction that several adverbial modifiers cannot be adjoined at the same node reflects our assumption that operators adjoined at the same node should be equivalent with respect to their scoping possibilities.
In the preceding section we have seen that we need multiple adjunction at single nodes since the scope parts of the quantifiers in (5) were adjoined to the same node. These scope components are lexically empty and in this case multiple adjoining does not increase the generative power of the grammar. However, if tree-local multicomponent derivations are combined with an unrestricted use of multiple adjunctions, the power of the formalism is beyond LTAG. Thus our restriction of not allowing multiple adjunctions at the same node in the case of adverbs is formally motivated also and not just from the linguistic considerations.
If multiple adjunction at the VP-node of *drives* is not allowed in (10), the only possible derivation is to adjoin *usually* to the VP-node of *drives*, and then to adjoin *allegedly* to *usually*. With this derivation, the desired restriction is obtained since the argument of *allegedly* is the label of $usually(h_1)$.

5 Island constraints

Island constraints for quantifier scope hold independently from specific quantifiers. In particular relative clauses are widely accepted to be islands for quantifier scope in the sense that quantifiers inside relative clauses cannot outscope the quantifier of the relativized NP (see Rodman 1976, Reyle 1993, Muskens 1995, Kallmeyer 1999).

(12) a. Every representative of most of the companies saw this sample.
b. Every person who represents most of the companies saw this sample.

In (12)a. *most of the companies* can have wide scope, whereas in (12)b., wide scope of the embedded quantifier *most of the companies* is not possible. The relative clause in (12)b. is an island for quantifier scope.

We claim that the difference between (12)a. and (12)b. follows from different kinds of derivations: In (12)a., the tree anchored by *representative* and *of* is an initial tree, whereas the relative clause tree with anchor *represents* in (12)b. is an auxiliary tree. This suggests that auxiliary trees constitute island whereas initial trees do not. In the dependency structure expressed by a derivation tree, auxiliary trees also mark some kind of islands in the following sense: Suppose that the edges in a derivation tree are directed from predicates to arguments. For substitutions we have downwards dependencies whereas for adjunctions we have upwards dependencies. Then, with an auxiliary tree the chain of downwards dependencies is interrupted and a new dependency tree begins. This observation suggests that islands follow not just from a technical difference between two tree operations but rather that quantifiers can rise to higher trees in the derivation structure as long as there is a downwards dependency relation. Based on this observation, island constraints can be read off the derivation structure as follows: Let the top of a semantic representation be defined as its topmost element with respect to subordination. (Subordination is the scope order given by the formulas and constraints in a semantic representation.) On the one hand, everything inside an auxiliary tree is "blocked" by the next higher tree: the top of the semantic representation σ_β of an auxiliary β must be below the top of the semantic representation of the tree to which β is adjoined. On the other hand, as long as there are only arguments added by substitution below an auxiliary β, everything inside these arguments can rise up to the top of σ_β, i.e. the tops of these arguments must be below the top of σ_β.

(13)

$l_1 : saw(x, x_2)$, $l_2 : every(x, h_2, h_3)$, $l_3 : person(x)$
$l_1 \leq h_1$, $l_1 \leq h_3$, $l_3 \leq h_2$, $l_2 \leq h_1$,
arg: x_2

We will illustrate this by showing a part of the analysis of (12)b. (13) is obtained by combinig the semantic representations for *saw*, *every* and *person*. Here $l_2 \leq h_1$ is an additional island constraint that has no effect in this case since *every* is added to the matrix clause. Next, the relative clause is adjoined to the NP-node taking x as an argument. After adding the semantic representations for *represents* and then for *who*, (14) is obtained, where $h_4 \leq h_2$ is an additional island constraint.

(14)

$l_1 : saw(x, x_2)$, $l_2 : every(x, h_2, h_3)$, $l_3 : person(x)$, $l_4 : represents(x, x_3)$
$l_1 \leq h_1$, $l_1 \leq h_3$, $l_3 \leq h_2$, $l_4 \leq h_4$, $l_2 \leq h_1$, $h_4 \leq h_2$
arg: x_2, x_3

Adding the quantifier *most* to *represents* gives (15). Here $l_5 \leq h_4$ and $h_4 \leq h_2$ ensure that *most* (label l_5) is in the restriction (and therefore the scope) of *every*.

(15)

$l_1 : saw(x, x_2)$, $l_2 : every(x, h_2, h_3)$, $l_3 : person(x)$,
$l_4 : represents(x, y)$, $l_5 : most(y, h_5, h_6)$, $l_6 : p_1(y)$
$l_1 \leq h_1$, $l_1 \leq h_3$, $l_3 \leq h_2$, $l_4 \leq h_4$, $l_4 \leq h_6$, $l_6 \leq h_5$
$l_2 \leq h_1$, $h_4 \leq h_2$, $l_5 \leq h_4$, $h_6 \leq h_4$
arg: x_2, p_1

Note that the locality of the TAG is responsible for the fact that quantifier scope trees inside a relative clause cannot be adjoined to the matrix clause. So the locality of the grammar together with the island constraints read off the derivation tree provide just the amount of underspecification needed for quantifier scope.

6 Related work

Among recent approaches to underspecified semantics, in particular Muskens & Krahmer (1998) and Kallmeyer (1999) are closely related to our work. Both proposals also separate scope information from predicate argument semantics. Muskens and Krahmer however do not adopt any locality constraint and therefore their use of underspecification is too general. Kallmeyer uses tree descriptions and makes use of the locality of TAGs. But in order to control the amount of underspecification that comes with the use of descriptions, rather complex formal definitions are necessary. This problem is avoided in our approach where syntactic structures are represented by trees and underspecification is used only in a very limited way for scope relations between propositional formulas.

7 Conclusion

In this paper, we have presented a compositional semantics for LTAG based on the idea of factoring predicate argument and scope semantics. The framework proposed here provides just the right amount of underspecification adequate for the analysis of scope ambiguities.

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The Dynamics of Tree Growth and Quantifier Construal

Ruth Kempson & Wilfried Meyer-Viol,
Department of Philosophy, King's College, London.

Abstract This paper demonstrates how quantifier-construal can be globally defined without sacrificing an incremental left-right process of projecting interpretation. Scope statements, collected during the course of the left-right parsing process and subject to lexically specified restrictions, are separated from the projection of content for quantifying expressions. Amongst other scope restrictions, construal of indefinites is shown to resemble pronominal anaphora, with indefinites defined as taking narrow scope with respect to some element determined by a free pragmatic choice.

In the search for an incremental projection of natural-language (NL) content following the flow of NL discourse, relative quantifier scope continues to provide a challenge, for no complete specification of content for quantified sentences can be given until scope is determined. Accordingly, relative quantifier construal is assumed to require some general rule at the clausal level. This leaves unresolved the problem of considerable lexical variation. First, unlike quantifiers such as *most*, *almost all*, indefinites in English are subject to free choice of scope either with respect to other terms already introduced in the interpretation of the string, or more restrictedly to terms that follow:

(1) Every professor decided 3 students should evaluate a recent MIT thesis.

(2) A student interviewed every professor.

This freedom is not reducible to a specific-nonspecific distinction in virtue of "intermediate-scope" interpretations displayed by indefinites possibly within a relative structure, hence not characterisable either as some form of "covert" movement subject to familiar syntactic restrictions (cf. Farkas 1981 and others following):

(3) Every professor submitted two reports that a student of mine had cheated.

Secondly, there is considerable lexical and cross-linguistic variation amongst this subclass of quantifiers, a variation which is problematic for any analysis of indefinites in which their construal is defined as a general process (Abusch 1993, Winter 1997). Many languages (eg Chinese) disallow the English option of interpreting a subject indefinite on some following quantified expression as in (2). Moreover, within English, indefinites vary, *a certain* imposing an anti-locality restriction that the scope of the indefinite may not be selected as narrow with respect to another quantifying expression in its clause, thus precluding an interpretation in (4) in which the singular indefinite is interpreted with narrowest scope:

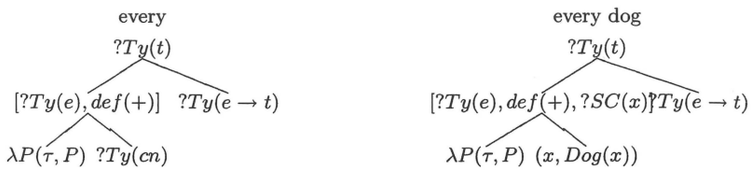

Figure 1: Development of an unreduced lambda term I.

(4) Every professor ensured that two students studied a certain syntactic puzzle.

There are also unexpected structural variations in scope potential, with dative and double object constructions, despite general denotational equivalence, differing in that only the dative construction allows inverse scope of an indefinite on the following NP:

(5) John showed a picture to every student

(6) John showed a student every picture.

Scope restrictions may also be imposed by individual items – eg English middle verbs preclude wide scope construal of their complement NP:

(7) Every recipe used a pound of flour.

In this paper, we address this challenge by defining quantifier-construal globally while nevertheless collecting relative scope statements as part of a left-right interpretation process. The effect is that lexical constraints and free pragmatic choices can both feed the algorithmic processes determining the content of quantified expressions.

The Model. The account is set within a structure-based model of interpretation in which a sentence-string is projected as a goal-driven construction of some unreduced lambda term of type t (Meyer-Viol 1997, Kempson et al forthcoming), through a process of progressively enriching partial representations. This lambda term is represented as a decorated tree, in which each node is introduced with requirements that are subsequently fulfilled by annotations, sub-expressions of the lambda term. Figure 1 through 5 shows the series of trees that arise in the parsing of a simple example such as 8:

(8) Every dog ate a biscuit.

The words of the sentence together with general rules induce *transitions* between *partial decorated trees*, by actions that introduce and decorate nodes. The semantic content of the final tree structure, corresponds to the *unreduced lambda term* $((\lambda x \lambda y[Ate(x)(y)](\tau, x, Dog(x)))(\epsilon, y, Biscuit(y))$ prefixed by an index of evaluation plus scope information. Now with the final tree reflecting the interpretation of the sentence, the non-terminal nodes are consecutively annotated

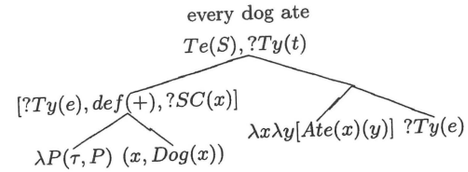

Figure 2: Development of an unreduced lambda term II.

— with 'reductions' — through a bottom-to-top process, to a propositional formula as annotation at the root node. The tree construction process is driven by a combination of computational, lexical, and pragmatic rules, the general constraint being that the process is monotonic.

Representation of quantified expressions. In this process, representations of quantified expressions are formed using *variable-binding term-operators* to give us terms of the form $(\epsilon, y, Biscuit(y))$ of type e, that is, the same type as, for instance, proper names. Disregarding scope, these representations are completely described by fixing three parameters. The BINDER ϵ indicates the mode of quantification (i.e. existential). The VARIABLE (i.e. y) indicates the variable being bound by the binder. The RESTRICTOR (i.e. $Biscuit(y)$) indicates the binding domain of the variable.

These three features exhaustively specify quantified NP denotations in isolation. However, to characterise NP's as occurring within a sentence, a fourth piece of information is required, an expression of the scope relations of that term within the sentence. A SCOPE statement is an atomic formula of the form $x < y$ stating, in this case, that the quantifier binding x has scope over the quantifier binding y.

Once these four features for quantified NP representations are fixed, the semantic, i.e., truth-functional, interpretation of a clause projection is fully determined.

More formally, we associate with a sentence representation ψ with bound variables $x_1, \ldots, x_n$ a strict partial order $\mathcal{B} = \langle B, <_{\mathcal{B}} \rangle$ where $B \subseteq \{x_1, \ldots, x_n\}$ and $<_{\mathcal{B}} \subseteq B \times B$ is an irreflexive, transitive relation on B. Such an ordering reflects a choice of scope constraints on the terms occurring in ψ. Consider our basic mixed-quantification example (8); on the interpretation reflecting the order of the words in the string, we have the pair, $(\mathcal{B}, \psi)$ where $\psi = Ate(\tau, x, Dog(x))(\epsilon, y, Biscuit(y)))$ and $<_{\mathcal{B}} = \{\langle x, y \rangle\}$ giving rise to the same truth-functional interpretation as $\forall x(Dog(x) \rightarrow \exists y(Biscuit(y) \wedge Ate(x, y)))$. If we have the reversed scope constraint, i.e., $<_{\mathcal{B}} = \{\langle y, x \rangle\}$, then ψ has the interpretation $\exists y(Biscuit(y) \wedge \forall x(Dog(x) \rightarrow Ate(x, y)))$.

Processing of quantified expressions. The processing flow when dealing with quantifiers is then as follows. At its introduction, having been culled from the natural language string, a quantified expression will receive an initial de-

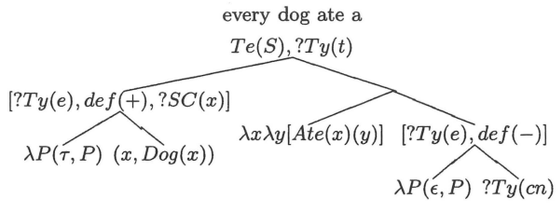

Figure 3: Development of an unreduced lambda term III.

scription where the binder derives from the determiner, and the variable and the restrictor derive from the common noun of the quantified NP. The result is an annotations of a tree node of type e. Thus, parsing through *Every dog ate a biscuit*, our example (8), the phrase *a biscuit* will initially be represented by $(\epsilon, y, Biscuit(y))$ and the phrase *every dog* by $(\tau, x, Dog(x))$. These terms are retained until the tree has been evaluated to the top node.

Associated with each such term, at its type e node, there is a scope requirement $?SC(\mathbf{x})$, contributed by the nominal, and an annotation $def(-/+)$ contributed by the determiner, together with whatever idiosyncratic restrictions may be imposed by individual items. The scope requirement is fulfilled once the nominal variable (bound to $\mathbf{x}$) is involved in some *scope statement* annotating some appropriate dominating node of type t. This statement indicates the scope of the element relative to other appropriate expressions in the resulting formula; it is, in effect, a quantifier storage device. The label $def(-/+)$ indicates whether we are dealing with an indefinite NP or not. If the NP under consideration is not an indefinite, then the scope it introduces follows the order of occurrence in the string: if the previous quantified NP had variable x and y is the variable bound by the current NP, then the statement $x < y$ is added to the first dominating node requiring type t.

In the case of indefinites, the scope is fixed as an anaphoric-like choice. The scoping statement associated with an indefinite quantifier Qy is completely free, apart from the fact that it must depend on something. (In cases of apparently widest scope, we presume it takes narrow scope with respect to an index of evaluation, represented as part of the formula.) In the actual parsing process, this is effected by the indefinite projecting a scope statement involving a meta variable to depend on. Subsequent PRAGMATIC substitution of this variable by some term out of those made available in the parse process then leads to a complete scoping. Because of the left-to-right nature of the parse, determining the scope structure of the eventual representation takes place in two stages. First the string is parsed and the representation is annotated with scope statements. In the second stage, these statements are used to construct a more familiar quantification structure. This strategy of collecting scope statements incrementally for later realisation enables lexically projected instructions to contribute idiosyncratic restrictions on scope construal (eg measure verbs induce a subject-

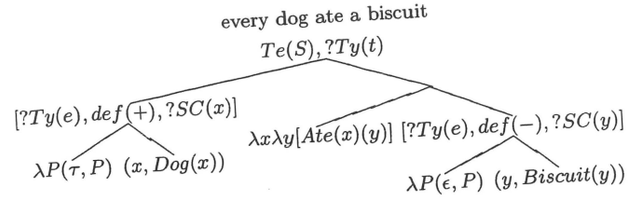

Figure 4: Development of an unreduced lambda term IV.

relative interpretation of their indefinite object).

Having parsed the string (8), the scope relations, however projected, appear as atomic propositions, scope statements, involving the bound variables on the root node. These statements have been collected in the course of the parse. The scope statements can now be used to algorithmically transform the formula (i.e. $Ate(\tau, x, Dog(x))(\epsilon, y, Biscuit(y))$) to more familiar shape (i.e. $\forall x(Dog(x) \rightarrow \exists y(Biscuit(y) \wedge Ate(x, y))))$ In this transformation the quantifier binding x indeed has scope over the quantifier binding y. The restructuring is guided by linear, connected and maximal $S < x_1 < \ldots < x_n$ chains in the set of scope statements. The end result will be a tree with a top node annotated by $Fo(\phi)$ such that the semantical interpretation of ϕ reflects the desired scope relations between the quantified NP's. For a formula ϕ in which the terms $(\nu_1 x_1 \psi_1), \ldots, (\nu_n x_n \psi_n)$ occur, the basic restructuring moves are of the form:

$$\frac{\ldots, S < x_1 < \ldots < x_n, \ldots, \phi[\nu x_n \psi_n / x_n]}{\ldots, S < x_1 < \ldots < x_{n-1}, \ldots, f_{\nu_n x_n \psi_n}(\phi),}$$

where for x occurring free in ϕ and S a (temporal) index, the values $f_{\nu x \psi}(\phi)$, for $\nu \in \{\epsilon, \tau, Q\}$, and $f_S(\phi)$ are defined by: (1) $f_{\tau x \psi}(\phi) = \forall x(\psi \rightarrow \phi)$, (2) $f_{\epsilon x \psi}(\phi) = \exists x(\psi \wedge \phi)$, (3) $f_{Qx\psi}(\phi) = Qx(\psi)(\phi)$, (4) $f_S(\phi) = (S : \phi)$. So the Q-evaluation rule consumes one variable, the last, from the scope sequence in order to restructure the formula. Iteration of this procedure will lead to S being the only variable left. This variable is then fixed to the front of the formula. For instance, the pair $\{S < x < y, Ate(\tau, x, Dog(x))(\epsilon, y, Biscuit(y))\}$ resulting from a parse of the example sentence is first transformed to $\{S < x, \exists y(Biscuit(y) \wedge Ate(\tau, x, Dog(x))(y))\}$, followed by $\{S, \forall x(Dog(x) \rightarrow \exists y(Biscuit(y) \wedge Ate(x)(y)))\}$ and finally $S : \forall x(Dog(x) \rightarrow \exists y(Biscuit(y) \wedge Ate(x)(y)))$.

The separation of NP content and NP scope provides a natural basis for characterising lexical variation. We take indefinites to project underspecified terms of type e, for this combination of lexical underspecification of content and typing enables the parallelism between indefinite and pronominal construal to be directly modelled — like anaphora resolution, indefinite construal involves a pragmatic substitution process, with a metavariable for the second argument of the projected scope relation fixing the scope relation prior to any determination

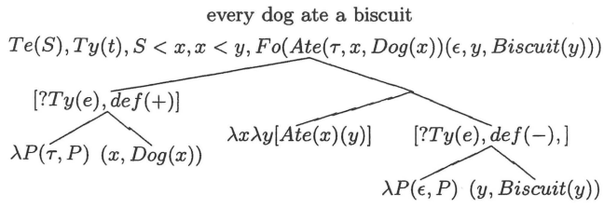

Figure 5: Development of an unreduced lambda term V.

of content. This substitution process may be subject to additional restrictions defined over the emergent structure, eg. the anti-locality restriction imposed by *a certain* analogous to that associated with pronouns, and, for the Chinese order-sensitive construal of indefinites, the projection of an object-level variable as the additional argument rather than a metavariable (to be interpreted as part of the lexical update process, hence allowing no delay). The difference between double object and indirect object constructions, despite their identical semantic configuration, can be straightforwardly expressed, given the characterisation of words as building up the required decorated tree. The sequence of actions induced by double NP sequences for particular verbs imposes the additional requirement on node development that the scope statement must not be one in which the term projected as the direct-object argument outscopes the projection of the indirect-object argument. The general significance of these results is that by defining interpretation in terms of transitions across partial tree structures integrating computational, lexical and pragmatic actions, we can articulate a fine-grained characterisation of quantifier-scope construals, sensitive to lexical, structural and pragmatic considerations, while retaining a fully algorithmic definition of semantic content for the resulting logical terms.

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Cumulativity & Distributivity Interaction of Polyadic Quantifiers

Sarah D. Kennelly & Fabien R. Reniers
UiL-OTS, Utrecht

Abstract

We show how to relate tri-adic quantifiers that express mixed readings of distributivity and cumulativity within a single 3-place predicate to the dyadic quantifiers that express distributivity (function composition of monadic quantifiers) and cumulativity (Scha 1981). We discuss problems with the standard approaches and propose that cumulativity necessarily takes precedence over distributivity. Consequently, for mixed readings cumulativity is reanalyzed as a quantifier that relates a type $\langle 1 \rangle$ and a type $\langle 2 \rangle$ quantifier. This new account of cumulativity generalizes conveniently to cumulative quantifiers of arbitrary type.

1 Introduction

This article discusses the systematic correspondences that exist between dyadic quantifiers that express distributivity and cumulativity and tri-adic quantifiers that express mixed readings of distributivity and cumulativity. Schein (1993) has also investigated these readings in terms of event-semantics, however the present analysis attempts to circumvent an event-based approach. As a working example we consider the 'mixed' reading of (1).

(1) 20 linguists sent 5 articles to 40 reviewers.

In (1) distributivity and cumulativity may be expressed simultaneously, under a reading whereby 20 linguists each sent 5 articles to a total of 40 reviewers. On this reading the NP *5 articles* is scope-dependent on the NP *20 linguists*, while *40 reviewers* is scope-independent. Another form of dependency relation does seem to hold, however, in that the number of reviewers totalizes with respect to the 20 linguists.

It is an easy task to articulate the intended interpretation of (1) in terms of a tri-adic quantifier: MIX(20,Linguist,5,Article,40,Reviewer). 'MIX' can be applied to the relevant relation (Send) if the information from the three NPs is supplied as parameters, as in (2).

(2) MIX(20,Linguist,5,Article,40,Reviewer)(Send) iff
$20(\text{Linguist})(\lambda x.\ 5(\text{Article})(\lambda z.\ \exists y\ \text{Reviewer}(y)\ \wedge\ \text{Send}(x,y,z))) \wedge$
$40(\text{Reviewer})(\lambda y.\ \exists x\ \text{Linguist}(x) \wedge 5(\text{Article})$
$(\lambda a.\ \exists r\ \text{Reviewer}(r) \wedge \text{Send}(x,r,a)) \wedge\ \exists z\ \text{Article}(z) \wedge \text{Send}(x,y,z))$

In this representation it is assumed that the numerals represent traditional determiners (i.e. '5' abbreviates $\lambda P.\, \lambda Q.\, [\ |P \cap Q| = 5\ ]$). Informally, (2) says that 20 linguists each sent 5 articles to reviewers and that 40 reviewers got articles from linguists who sent 5 articles to reviewers. This is termed the 'subject oriented' reading. There also exists an 'indirect-object oriented' reading whereby the articles vary with respect to the reviewers and it is the linguists who are scope-independent.

The problems posed by this type of reading are twofold. First, how can this interpretation (and therefore this tri-adic quantifier) be derived from current definitions of cumulativity and distributivity? Although cumulativity has already been defined in terms of polyadic quantifiers (Scha 1981), as has distributivity – at least in that distributivity always entails a scopal relation between the distributor and the distributee, and therefore can be represented in terms of function composition of monadic quantifiers – the composite of the two quantifiers poses interesting problems. Second, as the informal paraphrase of (2) suggests, the second reference to

linguists needs to identify the same group previously mentioned, but this is not made explicit in the formal representation. In this sense the formal representation only serves as an indication of the empirically attested interpretation.

The structure of this article is as follows. Section 2 discusses the derivation of the tri-adic quantifier. Section 3 addresses the problem of how to account for the crucial dependency relation. Finally, Section 4 summarizes the issues.

2 Derivation of the tri-adic quantifier

2.1 Cumulativity and distributivity in a polyadic setting

How can (2) be related to Scha's cumulative quantifier $[n,m](A,B)$ and distributivity expressed in terms of the function composition of two monadic quantifiers?

Scha's cumulative quantifier $[n,m](A,B)$ is defined in (3):

(3) $[n,m](A,B)(R^2)$ iff
$|Dom(R \cap A \times B)| = n \wedge |Rng(R \cap A \times B)| = m$

(3) is a dyadic quantifier that takes a two-place relation into a truth-value, given four parameters, viz. two numbers (n,m) and two noun sets (A,B). For example, consider the representation of *100 Aliens contacted 50 'ETs'* in (4), which amounts to saying that the number of ET-contacting aliens was 100 and the number of ETs contacted by aliens was 50.

(4) [100,50](Alien,ET)(Contact)

We propose to follow Keenan & Westerståhl (1997) in extending the definition of a generalized quantifier to apply to predicates of any arity. Using their terminology we call them monadic or type $\langle 1 \rangle$ quantifiers. They reduce the arity of a predicate by one. A GQ is thus used as the base case in the definition of the corresponding monadic quantifier M, mappping a n+1-ary relation (R^{n+1}) into a n-ary relation (R^n).

(5) $M(R^{n+1}) =_{\text{def}} \{\langle x_1,\ldots,x_n\rangle | GQ(\lambda y.\, R(x_1,\ldots,x_n,y))\}$

The definition in (5) is simplified to the extent that it is always the final argument of the relation which is reduced. The strategy in this definition is to fix all n arguments except the one to be reduced by the generalized quantifier, here y, and to retract them external to the scope of the generalized quantifier. Thus, a *polymorphic* monadic quantifier M is obtained[1] which makes it possible to use function composition in the construction of a dyadic quantifier $(M_1 \circ M_2)$ (i.e. type $\langle 2 \rangle$). The function composition of two monadic quantifiers M_1 and M_2 results in a scope-dependency, and therefore a distributive reading. This can be verified easily since function composition is an associative operation; $(M_1 \circ M_2)(R)$ is equivalent to the iterative $M_1(M_2(R))$.

2.2 Obvious integretation strategies fail

To integrate cumulativity and distributivity an obvious strategy to pursue is to apply the distributee *5 articles* in (1) to the Send-relation, obtaining the incorporation of the NP with the predicate, and then apply cumulation to the remaining arguments, as in (6).

(6) $[20,40]$(Linguist,Reviewer)$(\{\langle x,y\rangle | 5(\text{Article})(\lambda z.\, \text{Send}(x,y,z))\})$

[1] It is polymorphic. M reduces one-place relations to zero-place relations (truth values), two-place relations to one-place relations, etc. In other words, M is not restricted to any one type, so it is polymorphic. However, it is not (strictly) polyadic, since monadic quantifiers reduce relations only one place.

However, this strategy predicts that the number of articles varies with the number of linguist-reviewer pairs. Empirically the articles should distribute only with respect to the linguists.

Another way to go would be to quantify-in as in (7).

(7) $5(\text{Article})(\lambda z.\, [20,40](\text{Linguist,Reviewer})(\{\langle x,y\rangle | \text{Send}(x,y,z)\}))$

Of course this not an appropriate strategy, since the quantified-in element takes scope over the cumulative frame and in fact it must be scoped over in order to be distributed.

2.3 Proposal

We pursue the option that the distributive-cumulative interplay must be taken together in a tri-adic quantifier where function composition obtains within the cumulative semantics. Schematically:

(8) a. $(40R \bullet (20L \circ 5A))(\{\langle y,x,z\rangle | \text{Send}(x,y,z)\})$
b. $(20L \bullet (40R \circ 5A))(\text{Send})$

In (8) $20L$,$40R$ and $5A$ abbreviate the monadic quantifiers corresponding to the 20 linguists, 40 reviewers and 5 articles respectively. Apart from the function composition operator ($\circ$), we introduce a new cumulative operator ($\bullet$) that builds a tri-adic quantifier out of a monadic and a dyadic quantifier. (8a) represents the subject-oriented reading of (1) and (8b) represents the indirect-object-oriented reading.

Distributivity has already been defined in terms of the function composition of monadic quantifiers. Then the first step in the definition of the $\bullet$-operator is to also define cumulativity in terms of monadic quantifiers. It will then only be a small step to extend this operator in order to build a tri-adic quantifier from a monadic quantier and a dyadic quantifier, as needed in (8). Following Van der Does (1992), Scha's cardinality constraint in terms of numbers (n,m) (cf. (3)) may be generalized to determiners:

(9) $[D_1,D_2](N_1,N_2)(R^2)$ iff
$\exists S^2\, S = R \cap N_1 \times N_2 \wedge D_1(N_1)(dom(S)) \wedge D_2(N_2)(rng(S))$

From (9) there is a straightforward translation to the $\bullet$-operator:

(10) $(M_1 \bullet M_2)(R^2)$ iff
$\exists S^2\, S = R \cap \downarrow(M_1) \times \downarrow(M_2) \wedge M_1(dom(S)) \wedge M_2(rng(S))$

Where: $\downarrow(M)$ is the minimal live on set of M.

The use of the minimal live on sets permits us to abstract away from the reference to noun sets as used in (3).[2] This is advantageous when considering mixed readings and fully cumulative quantifiers of arbitrary type.

The second step in the definition of the $\bullet$-operator is to extend (10) to allow for dyadic input (D), translating into our final final proposal in (11).

(11) $(M \bullet D)(R^3)$ iff
$\exists S^3\, S = R \cap \downarrow(M) \times \downarrow(D) \wedge M(Arg_1(S)) \wedge D(Arg_{2,3}(S))$

Where:
$Arg_1(R^3) =_{\text{def}} \{x | \exists y\, \exists z\, R(x,y,z)\}$, and
$Arg_{2,3}(R^3) =_{\text{def}} \{\langle y,z\rangle | \exists x\, R(x,y,z)\}$

[2] We assume quantifiers to be conservative.

Note that the $\downarrow$-operator applied to dyadic quantifiers has not been defined. We will define $\downarrow (A \circ B)$ as $\downarrow (A) \times \downarrow (B)$. Under a natural extension of the minimal live on set operation to minimal live on relations[3] , this follows as a theorem[4] (E. Keenan p.c.).

Applying our final formulation of the $\bullet$-operator in (11) to our working example in (1) we arrive at the following semantics.

(12) $(40R \bullet (20L \circ 5A))(\{\langle y, x, z\rangle | \text{Send}(x, y, z)\})$ iff
$40R(\{y | \exists x\, \exists z\, \text{Linguist}(x) \wedge \text{Article}(z) \wedge \text{Send}(x, y, z)\}) \wedge$
$20L(5A(\{\langle x, z\rangle | \exists y\, \text{Reviewer}(y) \wedge \text{Send}(x, y, z)\}))$

Informally (12) says that a) 40 reviewers were sent articles by linguists and b) 20 linguists each sent 5 articles to reviewers. Clearly, the (b)-part is adequate as it gives the desired distributivity and, moreover, the existential closure over reviewers in the scope of the 5 articles is empirically attested (e.g. a particular linguist may send two of his articles to one reviewer and the remaining three to another reviewer). However, the (a)-part is too weak in one minor but crucial feature; it says that 40 reviewers were sent articles by linguists, which problematically may or may not be linguists from the original 20. This problem will be addressed in Section 3.

Finally, the strategy used to define the $\bullet$-operator can be used to systematically build fully cumulative quantifiers of arbitrary type. For example, the CUM3 quantifier below can be derived in terms of the $\bullet$-operators defined in (10) and (11): CUM3(M_1,M_2,M_3)(R^3) is equivalent to $(M_1 \bullet (M_2 \bullet M_3))(R^3)$. Crucially, $\downarrow (M_2 \bullet M_3)$ is equivalent to $\downarrow (M_2) \times \downarrow (M_3)$ if the $\downarrow$-operator applied to dyadic quantifiers is interpreted as the minimal live on relation.

(13) $\text{CUM3}(M_1, M_2, M_3)(R^3)$ iff
$\exists S^3\, S = R \cap \downarrow (M_1) \times \downarrow (M_2) \times \downarrow (M_3) \wedge$
$M_1(Arg_1(S)) \wedge M_2(Arg_2(S)) \wedge M_3(Arg_3(S))$

3 Dependency relations

This article has worked exclusively with the definition of cumulativity as proposed by Scha (1981) and elaborated by Van der Does (1992). Under their (and our) definition cumulativity is symmetrical. Yet, the informal paraphrase of (2) suggests an asymmetry in the semantics of mixed readings (and presumably in the semantics of cumulative readings): 20 linguist each sent 5 articles to reviewers and 40 reviewers were sent articles by some of *those* linguists. The problem is that the tri-adic quantifier $(40R \bullet (20L \circ 5A))$ does not accommodate the dependency indicated by *those*.

We leave a formal translation of this missing dependency within the cumulative semantics for further research. At the same time we observe that the desired strengthening is obtained if one assumes that the linguists in (1) are fixed in reference and treated as a plurality that is already present in the discourse[5], formalized in (14):

(14) $\exists X\, X \subseteq \text{Linguist} \wedge |X| = 20 \wedge (40R \bullet (D(X) \circ 5A))(\{\langle y, x, z\rangle | \text{Send}(x, y, z)\})$
Where: $D(X)(R^{n+1}) := \{\langle x_1, \ldots, x_n\rangle | \forall y \in X\, R(x_1, \ldots, x_n, y)\}$

(14) says that there is a collection of 20 linguists in the discourse such that these linguists each sent 5 articles to a total of 40 reviewers. The strengthening thus obtained shows that the problem encountered in (12) is independent of the interplay of cumulativity and distributivity and inherent to the definition of cumulativity as developed by Scha.

[3] D lives on R^2 iff for all $S^2 : D(S) \equiv D(S \cap R)$, where D is a dyadic quantifier.

[4] Let M_1 live on A and M_2 live on B, then $(M_1 \circ M_2)$ lives on $A \times B$ (given finite domains).

[5] Under this account the treatment of the NP *20 linguists* is not truly quantificational in that we use existential quantification over collections of linguists. For downward entailing NPs this could be problematic.

4 Conclusion

In this article we attempted to set out a systematic correspondence between two systems of quantification. We encountered unexpected problems when the quantifying-in or predicate integration strategies were applied to mixed readings. In our final solution we propose that function composition is nested within the cumulative semantics, attributing a dependency constraint within the cumulative reading.

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Using centering theory to plan coherent texts

Rodger Kibble and Richard Power, ITRI, University of Brighton.

1 Issues in Text Planning

This paper describes an approach to *text planning*, one of the distinct tasks identified in Ehud Reiter's "consensus" architecture for Natural Language Generation (Reiter 1994, Reiter and Dale 1997). This consists a "pipeline" of distinct tasks:

Text Planning - deciding the content of a message, and organising the component propositions into a text tree;

Sentence Planning - aggregating propositions into clausal units and choosing lexical items corresponding to concepts in the knowledge base;

Linguistic realisation - surface details such as agreement, orthography etc.

(See also (Cahill et al. 1999) who propose a more elaborate model which allows the "pipeline" as a concrete instantiation.) We assume that the component propositions to be realised in a text are organised in a tree structure in which terminal nodes are elementary propositions and non-terminal nodes represent discourse relations as defined by e.g., Rhetorical Structure Theory (RST, Mann and Thompson 1987). This structure only partially determines the linear order in which the propositions will be realised - in other words, any RST structure specifies a range of possible text plans. We propose as an additional constraint that the generator should seek to maximise *continuity of reference* as determined by the rules and constraints of centering theory, and we argue that this enables us to select the most cohesive variants from a set of text plans.

2 Centering in a nutshell

Centering theory (CT) is a theory of discourse structure which models the interaction of *cohesion* and *salience* in the internal organisation of a text. (See Grosz et al 1995; cf Hardt 1998 for a more formal treatment.) The main assumptions of the theory are:

1. For each utterance in a discourse there is precisely one entity which is the centre of attention or *center*. The center in an utterance U_n is the most grammatically salient entity realised in U_{n-1} which is also realised in U_n. This is also referred to as the *backward-looking center* or *Cb*.

2. There is a preference for consecutive utterances within a discourse segment to keep the same entity as the center, and for the center to be realised as Subject or *preferred center* (*Cp*). We refer to these principles as **cohesion** and **salience**

respectively. (Hardt's (1998) formalization only covers the first of these.) Pairs of successive utterances $\langle U_n, U_{n+1} \rangle$ are classified into the transition types shown in Fig. 1, in order of preference.

3. The center is the entity which is most likely to be pronominalised.

(**Note**: the notion of "salience" for the purposes of centering theory is most commonly defined according to a hierarchy of grammatical roles: SUBJECT > DIRECT OBJECT > INDIRECT OBJECT > OTHERS (see e.g., Brennan et al 1987). For alternative approaches see e.g., (Strube and Hahn 1999), (Walker et al 1994).)

CONTINUE: **cohesion** and **salience** both hold; same center (**or** $Cb(U_n)$ undefined), realised as Subject in U_{n+1};

RETAIN: **cohesion** only; i.e. center remains the same but is not realised as Subject in U_{n+1};

SMOOTH SHIFT: **salience** only; center of U_{n+1} realised as Subject but not equal to $Cb(U_n)$;

ROUGH SHIFT: neither **cohesion** nor **salience** holds.

Figure 1: Centering Transitions

3 Centering in NLG

CT has developed primarily in the context of natural language interpretation, focussing on anaphora resolution (see e.g., Brennan et al 1987). NLG researchers have applied CT to the tasks of Text Planning (Cheng MS), Sentence Planning (Mittal et al 1998) and choice of referring expression (e.g., Dale 1992). In this paper we concentrate on Text and Sentence Planning, aiming to determine whether the principles underlying the constraints and rules of the theory can be "turned round" and used as planning operators for generating coherent text.

It is not immediately obvious how the principles of **cohesion** and **salience** described above should be implemented in an NLG system following a Reiter-type "consensus" architecture. If we consider these principles as planning operations, **cohesion** naturally comes under Text Planning: ordering a sequence of utterances to maintain the same entity as the center, possibly within a partial ordering determined by discourse relations. According to (1) above, the center is defined by grammatical salience, which is determined by the Sentence Planner - for example, choice of active or passive determines whether an entity is realised as Subject. However, in a pipelined system the Text Planner does not have access to the sentence plan, yet it needs to know the identity of the center in order to

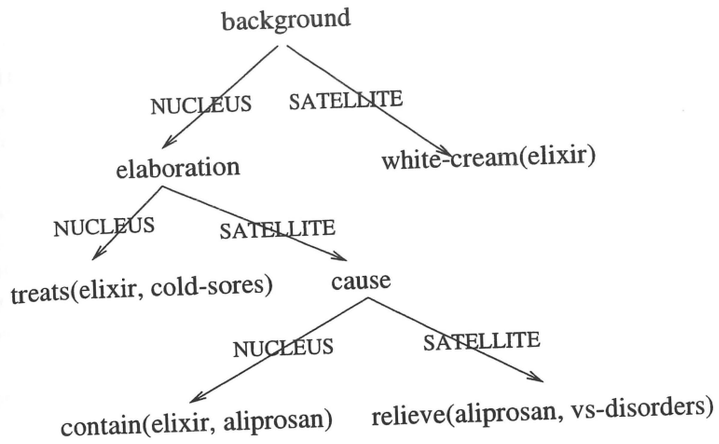

Figure 2: Rhetorical Structure

plan coherent text. One way out of this conundrum is to equate the center with the "topic" or "theme" of a sentence and require that this is given as part of the semantic input, so that centering rules merely reflect the information structure of a discourse. Kibble (1999) proposes an algorithm along these lines, but assumes that the "topic" is independently given by the text planner. An alternative strategy we will follow is to treat the task of establishing the Cb as an optimisation problem. In the process we relax the pipelining constraint a little and assume that certain options for syntactic realisation can be predicted on the basis of the argument structure of predicates, which is available at the stage of Text Planning.

4 Implemented prototype

Figure 2 shows a rhetorical structure (RS) that might serve as input to the text planner. The non-terminal nodes of the RS are labelled with RST relations; the terminal nodes are labelled with propositions, expressed in a simple semantic formalism. Obviously the RS allows eight possible orderings of the four propositions, depending on whether NUCLEUS precedes SATELLITE or vice-versa for each of the three rhetorical relations. For each ordering, there are many ways of distributing the propositions among text-categories such as sentences and paragraphs: at one (ridiculous) extreme, each proposition might be allotted a separate paragraph; at the other extreme, all four propositions might be placed in the same sentence. The number of possible text-plans increases further if we take account of the different ways in which rhetorical relations can be marked: for instance, cause can be expressed by the discourse markers 'since', 'so', and 'consequently' (among others), or it can be left unmarked, relying on the reader

to infer the relationship.

The ICONOCLAST system treats text planning as a constraint satisfaction problem (van Hentenryck 1989). The dimensions of variation among different text plans (order, text-category, discourse marker) are represented by variables ranging over finite domains, and constraints among these variables are applied so that incorrect solutions are ruled out (Power et al 1999). However, the number of correct solutions remains large (several hundred for the example in figure 2). To reduce them to a manageable set, the user can impose further constraints which eliminate solutions considered stylistically unacceptable; the user can also define criteria for *evaluating* solutions, so that even though many are still generated, they are ordered from best to worse.

To keep the example simple, let us assume that the following very strict constraints are applied:

- For the `background` relation, satellite precedes nucleus.
- For the `elaboration` relation, nucleus precedes satellite.
- The `cause` relation must be marked by 'since'; the other relations are unmarked.

For any ordering of the propositions, centering transitions are determined by the choices of *Cp* and *Cb*. Simplifying again, we will assume that the *Cp* can only be varied for the predicate `relieve`, which can be expressed in the active or passive, e.g., *Aliprosan [Cp] relieves viral skin disorders* vs *Viral skin disorders [Cp] are relieved by aliprosan.* Three sample text plans with *Cp* and *Cb* values specified are shown in figures 3-5. For each plan, an evaluation of centering transitions can be computed, for instance by assigning the following scores[1]:

`No Cb`	`0`
`Rough Shift`	`1`
`Smooth Shift`	`2`
`Retain`	`3`
`Continue`	`4`

Applying this evaluation to the three text plans we obtain the following percentage scores:

Plan A: $4 + 4 + 2 = 10/12 = 83\%$
Plan B: $4 + 4 + 1 = 9/12 = 75\%$
Plan C: $4 + 0 + 1 = 5/12 = 42\%$

These variants illustrate a best-case solution (Plan A), the worst case (Plan C) and an intermediate result (Plan B). Using pronouns for the *Cb* after CONTINUE, and demonstratives after SMOOTH SHIFT, the final texts for the three plans might be as in Figs 3-5.

[1] An alternative approach would be to score **salience** and **cohesion** independently, obtaining a *partial* preference ordering CONTINUE > { RETAIN | SMOOTH SHIFT } > ROUGH SHIFT

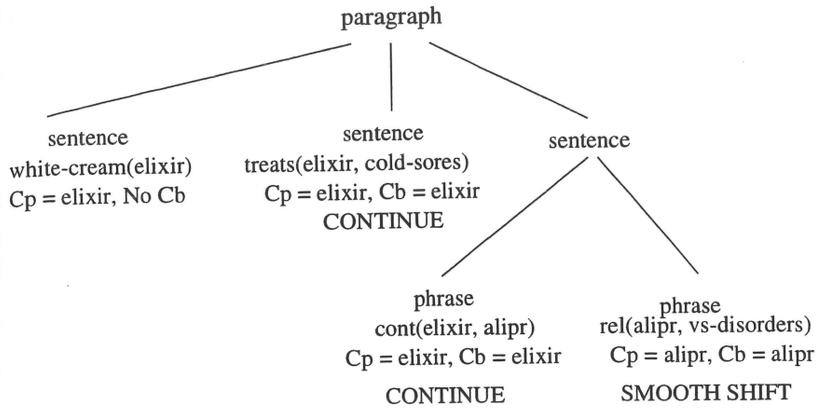

Figure 3: Text Plan A: *Elixir is a white cream. It is used in the treatment of cold sores. It contains aliprosan, since this relieves viral skin disorders.*

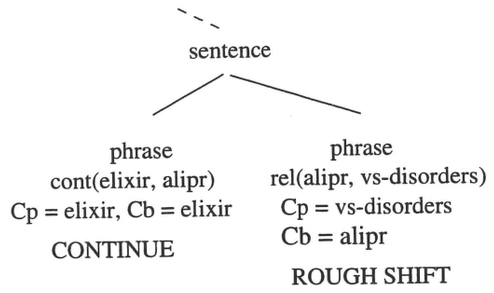

Figure 4: Text Plan B: ... *It contains aliprosan, since viral skin disorders are relieved by aliprosan.*

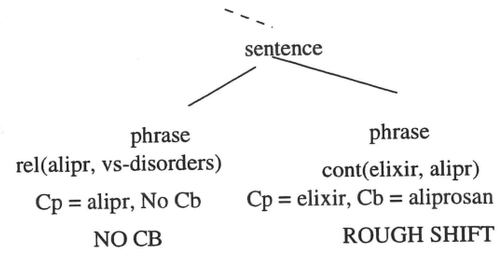

Figure 5: Text Plan C: ... *Since aliprosan relieves viral skin disorders, Elixir contains aliprosan.*

5 Conclusion

This paper has highlighted some implications of Centering Theory for planning coherent text. We show that by making some assumptions about which entities are potential *Cp*s, we can determine *Cb*s, *Cp*s, and hence transitions, in the text planning stage, thus allowing the text planner to select the proposition sequence that yields the best continuity of reference.

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DPL with control elements

Rick Nouwen
Utrecht institute of Linguistics OTS

1. Introduction Dynamic predicate logic (DPL) was introduced by Groenendijk and Stokhof [1] as a logic whose scoping mechanisms were more like those of natural language. One way of looking at DPL is thus as a language more suitable for specifying a semantics for natural language than ordinary predicate logic. Still, the language we speak is far more flexible than DPL.

In [5], Visser adds so-called *control elements* to DPL, thus constructing variants of DPL. In this paper we will push this construction to its limits by producing a dynamic predicate logic suited to give the semantics for so-called focal donkey conditionals. There are two interesting things about this fragment. First of all, it involves the processing of an alternative semantic value, for which there are no mechanisms in DPL available. Second, it is all about conditionals which cannot be accurately described by *dynamic implications*. In [1], dynamic implication was defined internally dynamic and externally static, parallel to the way conditionals behave in natural language. Focus[1] can break with these dynamic conventions, as is shown in (ii), where the anaphor finds its referent in the supposedly externally static conditional.

(i) If a farmer$_i$ owns a donkey$_j$, he$_i$ beats it$_j$.
*He$_i$ is mean.

(ii) If a FARmer$_i$ owns a donkey$_j$, he$_i$ beats it$_j$.
If an ARtist$_k$ owns it$_j$, he$_k$ treats it$_j$ well.

In section 2., I will give a rough sketch of an alternative semantics for focus within a dynamic framework. Section 3. introduces the idea of tuples as our central medium for information processing. We will define control elements as special instances of these objects. Then, in 4. we present the system itself and show how it deals with running examples (i) and (ii).

2. Alternative Semantics The key idea of Mats Rooth's *alternative semantics* [3] is that a focused constituent evokes a set of alternatives (the contrast set or p-set). This set creates an alternative semantic value at both local and global level.

(iii) Ruby shot [OSWALD].

Rooth assigns a value $[\![[\text{OSWALD}]]\!]^f$ to the focused object. This will be the set of all alternatives to Oswald. On the VP-level there will be an alternative semantic value as well, compositionally derived from Oswald's contrast set, which will be the set of entities E:[2]

(iv) $[\![\text{shot } [\text{OSWALD}]]\!]^f = \{\lambda x.\text{shot}(x, y) | y \in E\}$

Since our framework will be an algebraïc dynamic one, Rooth's lambda-based formal alternative semantics is of little use to us. We will have to say some things of how we are going to set up an alternative semantics within a dynamic semantic framework. We will stipulate three things on the semantics of focus, roughly based on Rooth's alternative semantics.

[1] By focus I mean deliberate stress on a constituent. I use small-caps to indicate a constituent in focus.

[2] This set will actually be restricted by the context. So if (iii) was a clarification of a misunderstanding over the murderer of John F. Kennedy, then the proper contrast set would have probably only included Oswald and Kennedy.

1. Focus on a constituent evokes a contrastive semantic value for this constituent.
2. In DPL this value can be given by what I will call p-formulas. Let $\rightsquigarrow$ represent a translation function from natural language to the language of DPL. Let $[A]_f$ denote that constituent A is in focus. We define $\rightsquigarrow_C$, a translation function from natural language to the corresponding p-formula recursively:
   - If $A \rightsquigarrow A'$ then $A \rightsquigarrow_C A'$
   - $[A]_f \rightsquigarrow_C \top$
   - If $AB \rightsquigarrow A' \varkappa B'$ and $A \rightsquigarrow_C A''$ and $B \rightsquigarrow_C B''$ then $AB \rightsquigarrow_C A'' \varkappa B''$
3. This contrastive semantic value has dynamic force. That is, it restricts the subsequent discourse, which must be seen in the light of the contrast caused by the focused constituent. This restriction is the cause of the deviate externally dynamic behavior of focal conditionals.

(1) is nothing more than a rather neutral formulation of Rooth's most basic thesis and (2) seems to me to be an adequate dynamic logical counterpart of Rooth's p-sets. The third point is best made clear by contrastive conditionals like (ii). After the first sentence in such a discourse is said, the contrastive semantic value states what is the subject of the contrast. Constructing the p-formula for the if-clause of (ii)'s first sentence would result in (v):

(v) $\quad \exists x; \top; \exists y; \mathrm{donkey}(y); \mathrm{own}(x, y)$

In other words: we are talking about things owning donkeys. Take this as a contextual restriction, insert it in the second sentence and we have a context for the second conditional, as well as a proper antecedent for the pronouns in it.
What is clear is that language is flexible enough to construct and use alternative semantic values. This means our variant must be able to produce alternative semantic values. In particular, it must be able to flexibly handle these values, even beyond sentence level.

3. Controlling information

Tuples of DPL-relations will play a central role in our semantic formalism. We will view these objects as a series of files, each file representing a relevant part of the semantics. For instance one of the files will contain the DPL-relation denoted by the p-formula, while another is reserved for the ordinary semantic value. Special cases of these tuples are the so-called *control elements* which will help steer the information to the right files. In the case of focus we will have to implement three kinds of information partitions: polarity, scope priority and dynamicity. Given the alternative semantics we discussed in the previous section, we would like the following partition of information regarding (ii):

(vi) If a [FARMER] owns a donkey, he beats it.
(1 / 0 / 1 / 0 ; d / s / d / s ; − / +)

+ and − denote polarity. Information in the antecedent clause is marked negative, while the consequent clause is transported to positive files. A parallel marking occurs with focus information. We want to mark the focused constituent as well as the consequent clause static (s) and allow dynamic reference (d) to the rest of the sentence. In order to deal with quantifier scope we mark NPs with a "1", meaning that they are in need of some priority. Notice that all the partitions we want are binary and have a clear default value (+, s and 0). This means that our control elements should work like switches. So for instance for polarity, we want an object

that changes the placing-convention for information from positive to negative as well as the other way around. One of our files in the tuples will therefor need to keep track of which placing-convention we are currently using. In fact, we would like two *polarity switchers*: one like the one we described and one doing the same thing with previous information, since we do not always know immediately that information we are passing is negative. This means our tuples will have to have two files keeping track of the current polarity. We will need parallel switches and tuple-files for focus. Scope only needs a forward switch.
In order to implement the switches we will use small monoids[3]. Let $\mathcal{P}$, $\mathcal{S}$, $\mathcal{F}$ be the monoids $\langle\{+,-\},\otimes,+\rangle$, $\langle\{0,1\},\oplus,0\rangle$, $\langle\{\mathsf{s},\mathsf{d}\},\diamond,\mathsf{s}\rangle$ with:

$\otimes$	$+$	$-$
$+$	$+$	$-$
$-$	$-$	$+$

$\oplus$	0	1
0	0	1
1	1	0

$\diamond$	s	d
s	s	d
d	d	s

Notice that each of these monoids has an identity element and a "switching element". Now we know what our tuples will look like. They will consist of files for DPL-relations as well as of files for values of $\mathcal{P}$, $\mathcal{S}$ and $\mathcal{F}$.
Let Q be a set of relations on assignments for which we have defined ';' as relation composition, '$\rightarrow$' as dynamic implication, 'id' as the identity relation and '$\bot$' as the empty relation. We define the set of tuples:

$$N := \{+,-\} \times Q^9 \times \{+,-\} \times \{0,1\} \times \{\mathsf{d},\mathsf{s}\}^2 \times Q$$

A pleasant way of talking about such tuples was suggested by Visser in [5]. We will view the fifteen-place tuples as functions on the set:

$$\Upsilon := \{\lhd,\ {-}\backslash^1,\ {-}\backslash^0,\ {+}\backslash^1,\ {+}\backslash^0,\ {_s}\backslash^1,\ {_s}\backslash^0,\ {_d}\backslash^1,\ {_d}\backslash^0,\ \pi, \rhd, \triangle, <, >, \Omega\}$$

Each element in this set represents a file in the tuple. For instance, $\lhd$ represents the file keeping track of the backwards polarity value and ${+}\backslash^1$ is a positive file in need of scope priority. Most important are π and Ω, representing the file for the p-formula and the container of the ordinary semantic value, respectively.
We will represent the tuples with the notation: $[\![\alpha : \phi, \beta : \psi, \ldots]\!]$. This is the tuple which has ϕ as value for file α and ψ as value for file β etc. Not mentioning a file in this notation will mean that it has it's default value, namely the identity element. Thus id, the identity tuple, can be represented as $[\![]\!]$. The definitions of the switches are now trivial. Note that we use the same symbol for the control element and for the file it works on.

$$\lhd := [\![\lhd : -]\!] \qquad \rhd := [\![\rhd : -]\!]$$
$$< := [\![< : \mathsf{d}]\!] \qquad > := [\![> : \mathsf{d}]\!] \qquad \triangle := [\![\triangle : 1]\!]$$

Moreover, let G be the set of relations on assignments such that:
- $\bot, \mathsf{id} \in G$
- $v \in \mathrm{Var} \Rightarrow \exists v \in G$ and
- $r_1, \ldots, r_n \in \mathrm{Var} \cup \mathrm{Con}$ & $P \in \mathrm{Pred}^n \Rightarrow P(r_1, \ldots, r_n) \in G$.

Now for any $g \in G$ we define the tuple $\vec{g}$:[4]

$$\vec{g} := [\![{+}\backslash^0 : g,\ {_s}\backslash^0 : g]\!]$$

In other words, the default convention for all information is placement in positive non-priority files and the placement of a "copy" in a static non-priority file. The need for this copy follows from the desire to create an alternative semantic value as soon as focus appears. The definition of (tuple-) composition (up next) will show how the different control elements for polarity and focus can change the conventions

[3] A monoid is a structure $\langle M, \times, \mathsf{id}\rangle$, where $\times$ is associative on M and $\mathsf{id} \in M$ is the identity element.
[4] In general we will drop the vector notation and confuse DPL-relations with their corresponding tuples.

concerning the two copies independently.
If α is a tuple and ϕ is in Υ, then we will write $\alpha(\phi)$ for the *value* of file ϕ in α. We define composition of tuples $q \cdot r := p$, with p defined as:

$$p(\lhd) := q(\lhd) \otimes r(\lhd) \qquad p(\rhd) := q(\rhd) \otimes r(\rhd) \qquad p(\triangle) := q(\triangle) \oplus r(\triangle)$$
$$p(<) := q(<) \diamond r(<) \qquad p(>) := q(>) \diamond r(>) \qquad p(\pi) := q(\pi) \cdot r(\pi)$$
$$p(\Omega) := q(\Omega) \cdot r(\Omega)$$

$$\gamma \in \{+,-\} \text{ and } \kappa \in \{0,1\} \Rightarrow\ p(\gamma\backslash^\kappa) := q(_{\gamma \otimes r(\lhd)}\backslash^\kappa) \cdot r(_{\gamma \otimes q(\rhd)}\backslash^{\kappa \oplus q(\triangle)})$$
$$\gamma \in \{\mathsf{s},\mathsf{d}\} \text{ and } \kappa \in \{0,1\} \Rightarrow\ p(\gamma\backslash^\kappa) := q(_{\gamma \diamond r(<)}\backslash^\kappa) \cdot r(_{\gamma \diamond q(>)}\backslash^{\kappa \oplus q(\triangle)})$$

The following valid identities will clarify the above definitions.

$$\triangle \cdot \triangle = \lhd \cdot \lhd = \rhd \cdot \rhd = < \cdot < = > \cdot > = \mathsf{id}$$
$$\lhd \cdot \rhd = \rhd \cdot \lhd$$
$$\triangle \cdot a = [\![+\backslash^1 : a,\ {}_s\backslash^1 : a,\ \triangle : 1]\!]$$
$$\rhd \cdot a \cdot \rhd = \lhd \cdot a \cdot \lhd = [\![-\backslash^0 : a,\ {}_s\backslash^0 : a]\!]$$
$$\triangle \cdot > \cdot a \cdot > = < \cdot \triangle \cdot a \cdot < = [\![+\backslash^1 : a,\ {}_d\backslash^1 : a,\ \triangle : 1]\!]$$
$$\rhd \cdot a \cdot > \cdot b \cdot \rhd \cdot > = \lhd \cdot a \cdot < \cdot b \cdot \lhd \cdot < = [\![-\backslash^0 : a; b,\ {}_s\backslash^0 : a,\ {}_d\backslash^0 : b]\!]$$

Typically, in a conditional a backward polarity switch $\lhd$ will rest inbetween if-clause and consequent-clause, thus transporting all information in the if-clause to files of switched polarity (which will be negative). We will control scope by placing scope switchers $\triangle$ around NPs. Parallel to polarity, we also have a backward and forward focus switch ($<$ and $>$). We have assumed that p-formula are an ultimate by-product of focus. We will use the focus-switches to construct this p-formula. This is done by making sure that all information in the if-clause, except for the focused constituent itself will be marked d. Later, the p-formula can be constructed from the information in the dynamic files and transported to π, which keeps track of contrast-information. All this is illustrated by (vii).

(vii) a. If a [FARMER] owns a donkey, he beats it.
b. $\triangle \cdot \exists x \cdot < \cdot \text{farmer}(x) \cdot > \cdot \triangle \cdot \text{own}(x,y) \cdot \triangle \cdot$
$\exists y \cdot \text{donkey}(y) \cdot \triangle \cdot > \cdot \lhd \cdot \text{beat}(x,y)$

The result of (vii)b. is a tuple corresponding to the partition in (vi). To be precise:[5]

(vii) c. $[\![-\backslash^1 : \exists x; \text{farmer}(x); \exists y; \text{donkey}(y),\ -\backslash^0 : \text{own}(x,y),$
$\mathsf{d}\backslash^1 : \exists x; \exists y; \text{donkey}(y),\ +\backslash^0 : \text{beat}(x,y),\ \lhd : -,$
$\mathsf{s}\backslash^1 : \text{farmer}(x),\ \mathsf{d}\backslash^0 : \text{own}(y),$
$\mathsf{s}\backslash^0 : \text{beat}(x,y),\ < : \mathsf{d}\ ]\!]$

4. E-DPL$^{\mathcal{W}}$ The set of tuples N defined in the previous section will now play a crucial part in our logic E-DPL$^{\mathcal{W}}$.[6] We will think of meaning as tuples of elements of N. The logic E-DPL$^{\mathcal{W}}$ consists of update functions defined on such meanings.[7] Let $s_1, \ldots, s_n \in N$ and let $n \geq 1$, if $\alpha \in N$ then:

$$\langle s_1, \ldots, s_n \rangle[\alpha] := \langle s_1, \ldots, s_{n-1}, s_n \cdot \alpha \rangle$$

In other words, the update-function corresponding to a tuple is simply the composition of that object to the tuple on the top of the stack.
We will next have to define an action which is able to evaluate the partitioned information. Without such a definition the control elements are meaningless. The

[5] When writing the values of files we constantly confuse formulas with the relation they denote.
[6] The logic presented here resembles the work presented by Vermeulen in [4] where an incremental sequence based semantics is constructed.
[7] For a more technical discussion of the logic, as well as some other versions, see [2].

test, as we will call it, constructs the dynamic implication out of negative and positive information, keeping scope priority in mind. The p-formula of the previous discourse acts as an extra restriction on this implication. The resulting relation is transported to the Ω-file. Furthermore, the π-file is updated with the current dynamic files.

$$\langle s_1, \ldots, s_n \rangle[?] := \langle s_1, \ldots, s_{n-2}, s^* \rangle$$

We are now free to state the details of s^* in terms of the two top tuples of the stack.

$$s^* := s_{n-1} \cdot [\![\pi : s_n({}_\mathsf{d}\backslash^1); s_n(_\mathsf{d}\backslash^0),$$
$$\Omega : (s_{n-1}(\pi); s_n(-\backslash^1); s_n(-\backslash^0) \rightarrow s_n(+\backslash^1); s_n(+\backslash^0))]\!]$$

Tests reduce the amount of tuples in the stack but thusfar we haven't defined anything which is creative. A very simple action called *fence* will provide for this.

$$\langle s_1, \ldots, s_n \rangle[\,[\,]\,] := \langle s_1, \ldots, s_n, \mathsf{id} \rangle$$

We introduce two more actions. The first enables us to reset focus-values. This will come in handy since thus-far we were forced to place an ad hoc focus switch on the place of the comma that separates the if-clause from the consequent-clause. This switch is absent when there is no focus in the if-clause. We will view the comma as a focus-resetter. The definition of the corresponding action is trivial.

$$\langle s_1, \ldots, s_n \rangle[\vdash\,] := \langle s_1, \ldots, s_{n-1}, s' \rangle$$

Here s' is defined as:

$$s' := [\![\gamma\backslash^\kappa : s_n(\gamma\backslash^\kappa), \lhd : s_n(\lhd), \rhd : s_n(\rhd), \triangle : s_n(\triangle), \pi : s_n(\pi), \Omega : s_n(\Omega)]\!]$$

The last action enables us to deal with negation. We want to treat negation as a special case of polarity with falsum as the only object in the positive files. This however also causes the need for a special test, since the implication which is the result of a formed negation should not end up in a safe Ω-file, but should be able to play an active part in the future. In particular: we want negations to be able to receive special polarity, scope and focus treatment themselves.
We introduce the negation-test:

$$\langle s_1, \ldots, s_{n-1}, s_n \rangle[¿] := \langle s_1, \ldots, s_{n-2}, \overline{s} \rangle$$

Again this test pops two tuples of the stack and pushes one back. This time we simply place the implication formed from the top tuple in two default files and concatenate to the next tuple.

$$\overline{s} := s_{n-1} \cdot [\![+\backslash^0 : \big(s_n(-\backslash^1); s_n(-\backslash^0) \rightarrow s_n(+\backslash^1); s_n(+\backslash^0)\big),$$
$$\mathsf{s}\backslash^0 : \big(s_n(-\backslash^1); s_n(-\backslash^0) \rightarrow s_n(+\backslash^1); s_n(+\backslash^0)\big)]\!]$$

These actions will prove to be enough to provide for a semantic analysis of focal conditionals.
One last definition is needed to complete our new logic, which we will call E-DPL$^{\mathcal{W}}$. Function composition for the update functions is defined trivially as:

$$\varsigma[\alpha\beta] := (\varsigma[\alpha])[\beta]$$

Since function application is associative, our system will be too.
The two illustrative discourses (i) and (ii) will show the logic at work. Here is how we give their semantics in terms of E-DPL$^{\mathcal{W}}$.

(i) If a farmer$_i$ owns a donkey$_j$, he$_i$ beats it$_j$.
*He$_i$ is mean.
[] $\triangle$ $\exists x$ farmer(x) $\triangle$ own(x,y) $\triangle$ $\exists y$ donkey$(y)\triangle$ $\lhd$ $\vdash$ beat(x,y) ?
[] mean(x) ?

(ii) If a FARmer$_i$ owns a donkey$_j$, he$_i$ beats it$_j$.
If an ARtist$_k$ owns it$_j$, he$_k$ treats it$_j$ well.
[] $\triangle$ $\exists x <$ farmer$(x) >$ $\triangle$ own(x,y) $\triangle$ $\exists y$ donkey(y) $\triangle$ $\lhd$ $\vdash$ beat(x,y) ?
[] $\triangle$ $\exists z <$ artist$(z) >$ $\triangle$ own(z,y) $\lhd$ $\vdash$ happy(y) ?

Applied to a neutral state $\langle \mathsf{id} \rangle$ the formulas result in a tuple consisting of a single tuple. Application of the formula in (i) results in:

$$\langle \, [\![\; \Omega : \; (\exists x; \text{farmer}(x); \exists y; \text{donkey}(y); \text{own}(x,y) \rightarrow \text{beat}(x,y)); \text{mean}(x) \;]\!] \, \rangle$$

Since there is no focus, the only non-default file is the omega-file. It consists of the normal DPL-translation of the incoherent discourse. As is desired the variable x is not in the scope of the previous sentence.
The application of (ii) shows us the working of the π-files. The second implication in the resulting omega-file is restricted by a previously built π-file.

$$\left\langle \left[\!\!\left[\begin{array}{ll} \pi : & \exists x; \exists y; \text{donkey}(y); \text{own}(x,y); \exists z; \text{own}(z,y) \\ \Omega : & (\exists x; \text{farmer}(x); \exists y; \text{donkey}(y); \text{own}(x,y) \rightarrow \text{beat}(x,y)); \\ & (\exists x; \exists y; \text{donkey}(y); \text{own}(x,y); \exists z; \text{artist}(z); \text{own}(z,y) \rightarrow \text{happy}(y)) \end{array} \right]\!\!\right] \right\rangle$$

5. Conclusions E-DPL$^{\pi p}$ is able to give a dynamic semantics of focus. The usage of control elements enables it to deal with alternative semantic values. The definition of the *test* implements the specific external dynamic behavior of focused conditionals. E-DPL$^{\pi p}$ is fully incremental and produces meanings in a very straightforward way, straight from the natural language word order.

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Semantics for Attribute-Value Theories

Rainer Osswald
Department of Computer Science
University of Hagen, Germany

Summary: Attribute-value (AV) descriptions are reconstructed from natural language by regimentation and formalization within first-order predicate logic. The introduction of appropriate predicate operators then leads to AV expressions of the usual Kasper-Rounds type. We present a slight extension which permits relations between attribute values. A straightforward modification of standard AV logic turns out to be sound and complete with respect to first-order derivability granted that attributes are functional. Demonstrating this is part of our second concern which is to apply geometric logic and locale theory to AV theories like HPSG. Viewing AV theories as propositional geometric theories provides a crisp characterization of the denotation of an AV theory as the point space of its classifying locale.

Attribute-Value Descriptions

The objective of attribute-value theories is to characterize the entities of the domain in question by characterizing their *attribute values* as being of a certain type or bearing certain relations to each other. Typical attribute values, say, of a person are its mother and its birthplace. *Attributes* thus are (dyadic) functional relations like that of mother to child or of place to offspring.

Natural language counterparts of AV descriptions are predicates of the form 'someone whose father is a plumber', 'someone whose wife hates his mother', or 'someone whose father is her employer'. The first predicate can be paraphrased by the regimented version 'x such that the father of x is a plumber', using variables as formalized pronouns. Writing '$\{x \mid \ldots x \ldots\}$' for '$x$ such that $\ldots x \ldots$', it can be rendered into '$\{x \mid P(\iota y F y x)\}$', with '$F$' for '$\{xy \mid x$ is father of $y\}$' and 'P' for 'plumber'. Elimination of the definite description leads to:

$$\{x \mid \exists y(Fyx \wedge Py) \wedge \forall yz(Fyx \wedge Fzx \rightarrow y = z)\}\,.$$

Presupposing 'F' as functional, that is,

$$\forall xyz(Fxz \wedge Fyz \rightarrow x = y)\,,^{1}$$

the foregoing predicate becomes equivalent to the *inverse image* or *Pierce product* '$\{x \mid \exists y(Fyx \wedge Py)\}$' of '$P$' by '$F$', abbreviated by '$F{:}P$'.

Polyadic predication as in the second example can be handled analogously, which leads to '$\{x \mid H(\iota y F y x, \iota y G y x)\}$' and further to '$\{x \mid \exists yz(Fyx \wedge Gzx \wedge Hyz)\}$', where '$F$' and '$G$' are again assumed to be functional and 'H' stands for '$\{xy \mid x$ hates $y\}$'. With '$\langle F_1, \ldots, F_n \rangle$' in place of:

$$\{y_1 \ldots y_n x \mid F_1 y_1 x \wedge \ldots \wedge F_n y_n x\}\,,$$

the predicate in question can be written as '$\langle F, G \rangle{:}H$', making use of the general definition of the Pierce product:

$$\{x_1 \ldots x_m \mid \exists y_1 \ldots y_n (F y_1 \ldots y_n x_1 \ldots x_m \wedge G y_1 \ldots y_n)\}\,.$$

[1] Beware! This definition of functionality follows Peano, Gödel, Tarski, and Quine contrary to the nowadays widespread convention to call 'F' functional iff $\forall xyz(Fxy \wedge Fxz \rightarrow y = z)$. Our definition of the Pierce product is a consequence of this decision.

The third type of predicate is subsumed by the second, with 'H' replaced by the identity predicate 'id', i.e. '$\{xy \mid x = y\}$'. A better known notation for '$\langle F, G\rangle$:id' is '$F \doteq G$'.

Reflexivity of attributes can be expressed using identity as an attribute because '$\langle F, \mathrm{id}\rangle$:id' is equivalent to '$\{x \mid Fxx\}$'. Finally, *attribute composition* is reverse relational composition. Notation: '$F|G$' for '$G \circ F$', i.e. for '$\{xy \mid \exists z(Fzy \wedge Gxz)\}$'.

Attribute-Value Logic

Attribute-value logic can be regarded as a *predicate-operator logic* in the sense of Quine (e.g. 1970). The following schemata are valid without additional assumptions as one easily verifies:[2]

(1) a. $P|\mathrm{id} \equiv \mathrm{id}|P \equiv P$
b. $(P|Q)|R \equiv P|(Q|R)$
c. $P{:}(Q{:}A) \equiv (P|Q){:}A$
d. $P{:}(A \vee B) \equiv P{:}A \vee P{:}B$
e. $\mathrm{id}{:}A \equiv A$
f. $P{:}\Lambda \equiv \Lambda$
g. $P{:}\mathrm{V} \equiv \langle P, P\rangle{:}\mathrm{id}$

Here, '$F \equiv G$' stands for '$\forall x(Fx \leftrightarrow Gx)$', '$F \vee G$' for '$\{x \mid Fx \vee Gx\}$', etc., as well as 'V' and 'Λ' for '$\{x \mid x = x\}$' and '$\{x \mid x \neq x\}$' respectively.

Using rules of inference like disjunction and transitivity and the fact that $A \subseteq B$ iff $B \equiv A \vee B$, a consequence of (1d) is that

(2) if $A \subseteq B$ then $P{:}A \subseteq P{:}B$.

To put predicate-operator logic to work once more, apply (2) to the valid schema '$Q{:}\mathrm{V} \subseteq \mathrm{V}$', which leads to (3c) using (1g) since, with (1c) and (1g), $\langle P|Q, P|Q\rangle{:}\mathrm{id} \equiv P{:}(Q{:}\mathrm{V})$. A further simple example is the derivation of (3a) from (1e) and (1g).

(3) a. $\mathrm{V} \subseteq \langle \mathrm{id}, \mathrm{id}\rangle{:}\mathrm{id}$
b. $\langle P, Q\rangle{:}\mathrm{id} \subseteq \langle Q, P\rangle{:}\mathrm{id}$
c. $\langle P|Q, P|Q\rangle{:}\mathrm{id} \subseteq \langle P, P\rangle{:}\mathrm{id}$
d. $\langle P_1, \ldots, P_n\rangle{:}A \subseteq \langle P_i, P_i\rangle{:}\mathrm{id}$

Presupposing attribute predicates as functional implies additional valid schemata, with proofs again an easy exercise.

(4) a. $\langle P, Q\rangle{:}\mathrm{id} \wedge \langle Q, R\rangle{:}\mathrm{id} \subseteq \langle P, R\rangle{:}\mathrm{id}$
b. $\langle P, Q\rangle{:}\mathrm{id} \wedge \langle P|R, P|R\rangle{:}\mathrm{id} \subseteq \langle P|R, Q|R\rangle{:}\mathrm{id}$
c. $\langle P_1, Q_1\rangle{:}\mathrm{id} \wedge \ldots \wedge \langle P_n, Q_n\rangle{:}\mathrm{id} \wedge \langle P_1, \ldots, P_n\rangle{:}A \subseteq \langle Q_1, \ldots, Q_n\rangle{:}A$

(5) a. $P{:}(A \wedge B) \equiv P{:}A \wedge P{:}B$
b. $P|\langle Q_1, \ldots, Q_n\rangle \equiv \langle P|Q_1, \ldots, P|Q_n\rangle$
c. $P{:}(\langle Q_1, \ldots, Q_n\rangle{:}A) \equiv \langle P|Q_1, \ldots, P|Q_n\rangle{:}A$

Attribute-Value Theories

If not otherwise specified, assume a fixed attribute-value signature, that is, a set L of elementary attribute predicates and sets A_n of n-adic sort predicates. Let in addition 'V' and 'Λ' count as monadic sort predicates and 'id' both as elementary attribute and as dyadic sort predicate. 'V', 'Λ', and 'id' will henceforth be denoted respectively by '$\top$', '$\bot$', and '$\mathbb{I}$'.

Primitive attribute-value descriptions are of the form $\ulcorner\langle p_1, \ldots, p_n\rangle{:}a\urcorner$, where the p_i's are possibly composed attribute predicates and a is an n-adic sort predicate. Attribute-value descriptions are then inductively constructed from these primitives by conjunction, disjunction, and attribute prefixing.

Attribute-value axioms are universally quantified conditionals, whose antecedents and consequents are attribute-value descriptions. An *attribute-value theory* is a set of such axioms. Since AV axioms are of the form $\ulcorner\phi \subseteq \psi\urcorner$, with ϕ and ψ AV descriptions, they can be regarded as ordered pairs of AV descriptions. AV theories thus correspond to dyadic relations on the set of AV descriptions. Notation: $\phi \preccurlyeq_T \psi$ iff $\ulcorner\phi \subseteq \psi\urcorner \in T$. An AV theory is *closed with respect to attribute prefixing* iff $p{:}\phi \preccurlyeq p{:}\psi$ whenever $\phi \preccurlyeq \psi$.[3]

Head-Driven Phrase Structure Grammar (HPSG) serves as an example. Typical axioms are: *sign* $\preccurlyeq$ *word* $\vee$ *phrase*, *word* $\wedge$ *phrase* $\preccurlyeq \bot$, and:

$$\mathrm{DTRS}{:}\textit{headed-struc} \preccurlyeq \langle \mathrm{SYNSEM|LOC|CAT|HEAD}, \mathrm{DTRS|HEAD\text{-}DTR|SYNSEM|LOC|CAT|HEAD}\rangle{:}\mathbb{I}\,.$$

An AV theory of particular importance is the theory *Avl* given by the following axiom schemata.

$\top \preccurlyeq \langle \mathbb{I}, \mathbb{I}\rangle{:}\mathbb{I}$ (*trivial reflexivity*)
$\langle p, q\rangle{:}\mathbb{I} \preccurlyeq \langle q, p\rangle{:}\mathbb{I}$ (*symmetry*)
$\langle p, q\rangle{:}\mathbb{I} \wedge \langle q, r\rangle{:}\mathbb{I} \preccurlyeq \langle p, r\rangle{:}\mathbb{I}$ (*transitivity*)
$\langle p, q\rangle{:}\mathbb{I} \wedge \langle p|r, p|r\rangle{:}\mathbb{I} \preccurlyeq \langle p|r, q|r\rangle{:}\mathbb{I}$ (*substitutivity*)
$\langle p|q, p|q\rangle{:}\mathbb{I} \preccurlyeq \langle p, p\rangle{:}\mathbb{I}$ (*prefix closure*)
$\langle p_1, \ldots, p_n\rangle{:}a \preccurlyeq \langle p_1, p_1\rangle{:}\mathbb{I} \wedge \ldots \wedge \langle p_n, p_n\rangle{:}\mathbb{I}$ (*reflexivity*)
$\langle p_1, q_1\rangle{:}\mathbb{I} \wedge \ldots \wedge \langle p_n, q_n\rangle{:}\mathbb{I} \wedge \langle p_1, \ldots, p_n\rangle{:}a \preccurlyeq \langle q_1, \ldots, q_n\rangle{:}a$ (*substitutivity*)

Since *Avl* collects (3) and (4) above, its axioms are theorems of the first-order theory *Fun* given by the axiom schema of attribute functionality. *Avl* will turn out to be complete with respect to first-order derivability in *Fun*.

Attribute-Value Systems

Since attribute-value theories are first-order theories, there is a standard model theoretic approach towards their semantics. Simply add *Fun*, which serves as background assumption, and take models of the extended theory.

If T is an AV theory then first-order models of $T \cup \textit{Fun}$ are called *attribute-value systems of* T. Such a model consists of a set U (the "universe") and a function M taking elements of L and A_n respectively to functional relations and n-adic relations on U. M extends as usual to first-order formulae and thus commutes with operators. For example, $M(p{:}\phi) = M(p){:}M(\phi)$.[4] Furthermore it is required that if $\phi \preccurlyeq_T \psi$ then $M(\phi) \subseteq M(\psi)$. Notice that every AV system is one of *Avl* because *Avl* axioms are *Fun* theorems, and that an AV system of a theory T is also one of the prefixing closure of T in view of (2) above.

Algebraizing Attribute-Value Theories

Identifying descriptions that are equivalent with respect to a theory T leads to the *Lindenbaum-Tarski algebra* of T. The standard quotient construction takes the set of equivalence classes and proves the induced algebraic operations to be well-defined. For our purposes the following step-by-step construction is more convenient.

Attribute composition is "algebraized" by regarding classes of equivalent attributes as elements of the free monoid L^* over L with operation $|$ and unit $\mathbb{I}$. The set of primitive AV descriptions can then be specified as (a representation of) $L^* \times L^* \cup \bigcup_{n>0}(L^*)^n \times A_n$, with operations $\langle\ \rangle$, and : restricted appropriately. Here we make use of the observation that $\langle p, q\rangle{:}\mathbb{I}$ can be seen as a representation of the ordered pair of p and q, which gives rise to the first direct summand.

[2] Schemata (1a) to (1e) are part of the definition of *Boolean modules* and *Pierce algebras*, (1f) ensures normality; see e.g. Brink et. al., 1997.

[3] Closure with respect to prefixing virtually resembles the so-called *master modality* applied to conditional constraints; see e.g. Rounds, 1997.

[4] It is important to note that the expression to the right of '=' denotes the Pierce product of *sets*. In other words, M interpretes predicate abstracts as names of subsets of U.

General AV descriptions are now obtained as elements of the distributive lattice freely generated by the set of primitives. Prefixing by p corresponds to the lattice homomorphism induced by the function defined for generators as follows: $p{:}(\langle q_1,\ldots,q_n\rangle{:}a) = \langle p|q_1,\ldots,p|q_n\rangle{:}a$. It remains to add $\top$ and $\bot$.

So far, identification is limited to conjunction, disjunction, and prefixing. Neither *Avl* nor any other AV theory is taken into account. This will be done below within the more general setting of possibly *infinite* disjunctions. Though not employed here it would allow, for example, to include regular attribute equations. And from a technical prespective the gain clearly makes up for the load.

Geometric Theories and Classifying Locales

According to Vickers (1999), *propositional geometric formulae* over a set G of primitives or *subbasics* are built from G by $\wedge$ and $\bigvee$ including $\top$ and $\bot$. More exactly, formulae are elements of the *frame* $\mathcal{F}(G)$ *freely generated by* G. In this context, a *frame* is a poset, ordered by $\leqslant$, with finite meets and arbitrary joins such that $a \wedge \bigvee S = \bigvee\{a \wedge b \mid b \in S\}$. *Frame homomorphisms* are functions preserving finite meets and arbitrary joins. $\mathcal{F}(G)$ is characterized up to isomorphism by the property that there is a function η from G to $\mathcal{F}(G)$ such that every function v from G to a frame A factors uniquely through η and a frame homomorphism $\overline{v}$ from $\mathcal{F}(G)$ to A. $\mathcal{F}(G)$ is, for example, the ideal completion of the distributive lattice freely generated by G.[5]

A *propositional geometric theory* T consists of a set G and a dyadic relation $\preccurlyeq$ on $\mathcal{F}(G)$. Members of $\preccurlyeq$ are *axioms* of T. The theory is *finitary* if the formulae of its axioms are finitely constructed from G by meet and join. A *model of* T *in a frame* A or *A-valued model of* T is a function v from G to A such that if $a \preccurlyeq b$ then $\overline{v}(a) \leqslant \overline{v}(b)$. A model of T in a frame is *universal* iff every model of T factors uniquely through it by a frame homomorphism. Such a frame $\mathcal{U}(T)$ is called *the frame presented by* T. It can be constructed by *geometric deduction* as the quotient frame of $\mathcal{F}(G)$ modulo the closure of $\preccurlyeq$ with respect to *reflexivity* and *transitivity* such that $a \preccurlyeq b \wedge c$ iff $a \preccurlyeq b$ and $a \preccurlyeq c$, and $\bigvee S \preccurlyeq b$ iff $a \preccurlyeq b$ for every element a of S. If T is finitary, one can proceed first without infinite joins and then do ideal completion.

A subset of G is *T-saturated* if its characteristic function is a $\mathbf{2}$-valued model of T, with $\mathbf{2} = \{\bot, \top\}$. Let $A^\star$ be the set of frame homomorphisms from a frame A to $\mathbf{2}$. By definition, there is a one-to-one correspondence between $\mathcal{U}(T)^\star$ and the set of $\mathbf{2}$-valued models of T.

Following Vickers (1989) we define a locale to be a topological system of a certain form. A *topological system* consists of a set X of *points*, a frame A of *opens*, and a *satisfaction* relation $\models$ borne by points to opens respecting meet and join. A *locale* is a topological system isomorphic to one with frame A, point space $A^\star$, and satisfaction defined such that $x \models a$ iff $x(a) = \top$.

The *classifying locale* $\mathcal{L}(T)$ of a theory T is a/the locale whose frame is presented by T. Its points thus are the $\mathbf{2}$-valued models of T, the *T-saturated* subsets of G, or any other equivalent representation with satisfaction defined appropriately.

Theorem: The classifying locale of a finitary theory *has enough points*, that is, if b is satisfied by every point satisfying a then $a \leqslant b$ ∎[6]

In other words, finitary geometric deduction is *complete*.

[5] e.g. Johnstone, 1982.

[6] See e.g. Johnstone (1982) or Vickers (1989) for a proof, which employs, unsurprisingly, the Prime Ideal Theorem.

Attribute-Value Structures and Completeness

An attribute-value theory T can be seen as a geometric theory over the set of primitive attribute-value descriptions. Points of the classifying locale $\mathcal{L}(Avl \cup T)$ are called (*abstract*) *attribute-value structures of* T.

Each AV structure x determines an AV system, i.e. a first-order model of *Fun* as follows.[7] First note that the set of subbasics satisfied by x is *Avl*-saturated and that its intersection with $L^* \times L^*$ is a conditional right congruence with respect to $|$ with prefix-closed field. Now take $\{[p] \mid x \models \langle p, p\rangle{:}\mathbb{I}\}$, where $[p]$ is the congruence class of p, as universe U_x, and define M_x such that

$$\begin{aligned} M_x(l) &= \{([p|l],[p]) \mid x \models \langle p|l, p|l\rangle{:}\mathbb{I}\} \\ M_x(a) &= \{([p_1],\ldots,[p_n]) \mid x \models \langle p_1,\ldots,p_n\rangle{:}a\} \end{aligned}$$

for elementary attributes l and n-adic sort predicates a. One easily checks that $M_x(l)$ and $M_x(a)$ are well-defined and that $M_x(l)$ is functional.

Lemma 1: $[\mathbb{I}] \in M_x(\langle p_1,\ldots,p_n\rangle{:}\phi)$ iff $([p_1],\ldots,[p_n]) \in M_x(\phi)$.

Proof: $M_x(\langle p_1,\ldots,p_n\rangle{:}\phi)$ coincides with $\langle M_x(p_1),\ldots,M_x(p_n)\rangle{:}M_x(\phi)$, and $[\mathbb{I}]$ is an element of the latter iff, by definition, there are congruence classes $u_1,\ldots,u_n$ such that $(u_i,[\mathbb{I}]) \in M_x(p_i)$ and $\langle u_1,\ldots,u_n\rangle \in M_x(\phi)$, in which case u_i necessarily equals $[p_i]$ since $M_x(p_i)$ is functional ∎

"Truth Lemma": $[\mathbb{I}] \in M_x(\phi)$ iff $x \models \phi$.

Proof: According to Lemma 1, $[\mathbb{I}] \in M_x(\langle p_1,\ldots,p_n\rangle{:}a)$ iff $([p_1],\ldots,[p_n]) \in M_x(a)$, that is, by definition, iff $x \models \langle p_1,\ldots,p_n\rangle{:}a$. Furthermore, M_x and satisfaction both respect meet and join ∎

Lemma 2: If T is a prefixing-closed AV theory then for every AV structure x of T, U_x and M_x define an AV system of T.

Proof: Suppose that $\phi \preccurlyeq_T \psi$ and $[p] \in U_x$. By assumption, if $x \models p{:}\phi$ then $x \models p{:}\psi$. By Truth Lemma and Lemma 1 this implies that if $[p] \in M_x(\phi)$ then $[p] \in M_x(\psi)$ ∎

The following *completeness* theorem recaptures and slightly generalizes Moshier (1993) and Osswald (1999).

Theorem: If T is a finitary attribute-value theory then finitary geometric derivability in $T \cup Avl$ plus prefixing is equivalent to first-order derivability in $T \cup Fun$.

Proof: It remains to prove completeness of geometric derivability plus prefixing. Suppose $T \cup Fun \vdash \phi \subseteq \psi$. For every AV structure x of the prefixing-closure $\overline{T}$ of T, M_x determines according to Lemma 2 a model of $T \cup Fun$. By Truth Lemma, if $x \models \phi$ then $[\mathbb{I}] \in M_x(\phi)$, and therefore $[\mathbb{I}] \in M_x(\psi)$, that is, $x \models \psi$. Thus $\phi \leqslant \psi$ in $\mathcal{U}(\overline{T} \cup Avl)$ because the classifying locale of a finitary theory has enough points ∎

Negation and Implication

There are several possibilities to express *negation* within geometric logic, for example as axioms $a \preccurlyeq \bot$. Or introduce additional primitives $-a$ plus axiom schemata $a \wedge -a \preccurlyeq \bot$ and $\top \preccurlyeq a \vee -a$.

As for a *conditional*, note that frames are, as ordered sets, indistinguishable from complete Heyting algebras, with $a \Rightarrow b = \bigvee\{c \mid c \wedge a \leqslant b\}$. But beware: $\top \preccurlyeq a \Rightarrow b$ has in general not the same effects as $a \preccurlyeq b$. Overlooking this difference has led Pollard and Sag (1987) to an inadequate conception of conditional information; see Osswald (1999).

[7] The construction if of course standard; cf. e.g. Rounds, 1997.

Reflections

One might ask what we have revealed about the semantics of attribute-value theories since we neither did consider the meaning of specific sort and attribute predicates, nor the nature of the entities those predicates are ascribed to, nor criteria for justifying such ascriptions. These are of course central issues for an empirical theory about a certain domain as e.g. HPSG intends to be one for linguistics. What we did, at least, is to straighten the discussion of such questions by explicating the referential structure of AV descriptions as regimented and formalized natural language predicates. Moreover, in our formulation AV theories consist of universally quantified conditionals and thus are of a form desirable for scientific theories.

Our main point was to define the formal denotation of an AV theory, or, to put it another way, to reveal *the ontology an AV theory defines by itself*. As emphasized by Quine (e.g. 1969), a theory determines an identity predicate by *identification of indiscernibles* and tying down criteria of identity is all what matters to ontology. For an AV theory T this means to look for a set X of "generic" entities together with a satisfaction relation borne by these entities to AV descriptions such that two elements x and y of X are identical iff they satisfy the same descriptions modulo equivalence in $T \cup Fun$. A further requirement which suggests itself is to choose X "as large as possible" so that for every pair of non-equivalent AV descriptions there is an element of X satisfying one of them but not the other. On account of our completeness result these two properties determine X to be the point space of a classifying locale of (the prefixing-closure of) T, whose uniqueness up to isomorphism nicely reflects Quine's conception of *ontological indifference*.

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Modeling Coalitional Power in Modal Logic

Marc Pauly (CWI, Amsterdam)

Abstract

Given a set of states, we introduce models which associate with every state a strategic game between a finite set of players which will result in a new state when played. The power of coalitions of agents in these games can be captured by the notion of α-effectivity, as studied in social choice theory: A coalition of players is α-effective for a set of states X if the coalition can guarantee an outcome in X. We propose a modal logic to formalize reasoning about α-effectivity, where $\langle C \rangle \varphi$ expresses that coalition C is α-effective for φ.

1 From Individual to Collective Actions

Modeling actions and their effects is a task which has occupied many researchers in computer science, logic, economics and philosophy. In the simplest case, we have one agent (person, process) who can choose between taking different actions which change the state of the world in various ways. A simple model of this scenario will contain an accessibility relation R which associates to every state of the world all those states which the agent can bring about through his actions, i.e. sRt holds if the agent can act as to bring about state t. In modal logic, one introduces a language to talk about such *Kripke* models: $\Diamond\varphi$ expresses that the agent can act in such a way that φ will be true after his action.

This simple one agent case can easily be extended to many agents by considering a relational structure which contains an accessibility relation R_i for every agent i, where $\Diamond_i\varphi$ expresses that agent i can bring about φ. The problem with such a multi-agent action logic is that it considers the different agents in isolation. Given a state s_0, agent 1 may act to bring about state s_1 and agent 2 may act to bring about state s_2, but what happens if both of them act simultaneously in s_0? Since the actions of the two agents will often not be independent but interact with each other, a more general model of action should associate a resulting state with every pair of actions (a_1, a_2) of the two players rather than with actions of the players individually.

Consider as an example the following situation: A political committee $C = \{1, 2, 3, 4, 5, 6\}$ consisting of six members has to decide whether or not to change a certain law. Two modifications of the law a and b are under discussion. The decision procedure used is the following. First, a subcommittee $C' = \{2, 3, 4\}$ votes on which modification to propose. Next, the whole committee votes on whether to adopt the proposed modification or to maintain the status quo q. We assume that in each case, the majority of the votes is decisive (no abstentions are allowed), and in case of a tie in the second vote, the vote of the chairman 1 will determine the outcome.

In the first voting round, the actions of members 2, 3 and 4 are taken simultaneously and jointly determine what will be voted on in the second round, so we need a model of collective action to represent this situation. Furthermore, different coalitions of members have different powers: Coalition $\{1, 2, 3\}$ can force any outcome a, b or q to be accepted. Coalition $\{1, 4, 5\}$ on the other hand is weaker, since it can only maintain the status quo or change it, but it has no

power to decide how it should be changed. Coalition $\{4,5,6\}$ finally has even less power since it cannot guarantee any outcome.

In this extended abstract, we provide a modal logic based on a general collective action model which can describe such situations. Given a set of agents N, we consider models where at every state, the agents take actions which together determine the resulting state. This amounts to associating a strategic game (form) with every state of the model where the outcomes of the game are states of the model again. In section 2, we relate two notions of *effectivity* to these games, formalizing what it means for a coalition of agents to have the ability to force a certain set of outcomes in a strategic game. The notion of α-effectivity will then be used as the basic semantic notion for the modal logic we develop in section 3. For a set of agents $C \subseteq N$, our modal language will contain formulas $\langle C\rangle\varphi$ which express that the group of agents C can bring about φ, i.e. is α-effective for φ. In the last section, we mention some links between our multi-agent action model and process algebra, also suggesting some further applications in the theory of repeated games (section 4).

2 Strategic Games and Effectiveness

As mentioned in the introduction, we would like an action model where at each state, the actions taken by the agents collectively determine the resulting state. To obtain such a model, we associate a strategic game with every state of the world. A *strategic game* $G = (N, \{\Sigma_i | i \in N\}, o, S)$ consists of a nonempty finite set of agents or players N, a nonempty set of strategies or actions Σ_i for every player $i \in N$, a nonempty set of outcome states S and an outcome function $o : \Pi_{i\in N}\Sigma_i \to S$ which associates with every tuple of strategies of the players (strategy profile) an outcome state in S.

In game theory [7, 3], strategic games also come equipped with a preference relation $\succeq_i \subseteq S \times S$ for every player $i \in N$ which indicates which outcomes a player prefers. Strictly speaking, our strategic games are only game *forms* which can be turned into a game by adding these preference relations.

For notational convenience, let $\sigma_C := (\sigma_i)_{i\in C}$ denote the strategy tuple for coalition $C \subseteq N$ which consists of player i choosing strategy $\sigma_i \in \Sigma_i$. Then given two strategy tuples σ_C and $\sigma_{\overline{C}}$, $o(\sigma_C, \sigma_{\overline{C}})$ denotes the outcome state associated with the strategy profile induced by σ_C and $\sigma_{\overline{C}}$.

Since the modal logic we aim for will contain expressions to talk about what coalitions of players can bring about in a game, we introduce two semantic notions which capture two different kinds of ability [6, 1]. Given a game G, a coalition $C \subseteq N$ will be *α-effective* for a set $X \subseteq S$ iff the coalition has a joint strategy which will result in an outcome in X no matter what strategies the other players choose. Formally, the *α-effectivity function* $E^\alpha_G : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ of a game G is defined as

$$X \in E^\alpha_G(C) \text{ iff } \exists\sigma_C \forall\sigma_{\overline{C}}\ o(\sigma_C, \sigma_{\overline{C}}) \in X$$

As to the second weaker kind of ability, call a coalition $C \subseteq N$ *β-effective* for a set $X \subseteq S$ iff for every joint strategy of $\overline{C}$, the coalition C has a joint strategy which will result in an outcome in X. Formally, the *β-effectivity function* $E^\beta_G : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ of a game G is defined as

$$X \in E^\beta_G(C) \text{ iff } \forall\sigma_{\overline{C}} \exists\sigma_C\ o(\sigma_C, \sigma_{\overline{C}}) \in X$$

β-effectivity is a weaker notion that α-effectivity since for every game G:

$$X \in E^\alpha_G(C) \Rightarrow X \in E^\beta_G(C)$$

whereas the converse does not hold in general. In case we have a game G such that $E^\alpha_G = E^\beta_G$ we say that G is *tight*. Tightness can be considered a generalization of determinacy: Consider a game $G = (\{1,2\}, \{\Sigma_1, \Sigma_2\}, o, \{Win1, Win2\})$. If G is tight, we know that either player 1 has a winning strategy (i.e. $\{1\}$ is α-effective for $\{Win1\}$) or $\{2\}$ is β-effective for $\{Win2\}$. In the second case, player 2 has a winning strategy by tightness.

Characterizing α-effectivity

Besides looking at effectiveness in strategic games, the notion of effectiveness can also be investigated more generally. For a set of agents N and a set of outcomes S, an *effectivity function* is any function $E : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ which associates to every coalition $C \subseteq N$ the sets of outcomes for which the coalition is effective, i.e. $X \in E(C)$ iff C is effective for X. This general notion has been investigated in [6, 1] and finds application in the theory of social choice [5] where the agents are voters who try to force certain election outcomes.

Given this intended interpretation of effectivity functions, it is natural to require them to satisfy certain properties, e.g. if a coalition C is effective for a set of outcomes X, it should also be effective for $X' \supseteq X$. Which properties we require will depend on the exact situation we want to model. Call an effectivity function $E : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ *outcome-monotonic* iff for all $X \subseteq X' \subseteq S$ and for all C, if $X \in E(C)$ then $X' \in E(C)$. E is *C-maximal* if for all X, if $\overline{X} \notin E(\overline{C})$ then $X \in E(C)$. E is *maximal* iff for all coalitions C it is C-maximal. Finally, E is *superadditive* if for all X_1, X_2, C_1, C_2 such that $C_1 \cap C_2 = \emptyset$, $X_1 \in E(C_1)$ and $X_2 \in E(C_2)$ imply that $X_1 \cap X_2 \in E(C_1 \cup C_2)$.

The question to be examined here is which effectivity functions are α-effectivity functions of some strategic game. As we will see in the next section, this characterization result will be very useful when formulating the semantics of coalition logic, since it allows us to dispense with strategic games by only talking about effectivity functions. Two such characterization results have been obtained in [6, 8]. However, these assume that the outcome function o of a strategic game is surjective, whereas we do not want to assume that every state can be reached provided that the players pick the right strategies; certain states (such as paradise) may be unreachable no matter how the players play. Thus, while the proof of theorem 1 below makes use of the techniques applied in [6, 8], it generalizes the results obtained previously.

We now introduce the combination of properties needed to characterize α-effectivity functions. Call an effectivity function $E : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ *playable* iff (1) $\forall C \subseteq N :\ \emptyset \notin E(C)$, (2) $\forall C \subseteq N :\ S \in E(C)$, (3) E is N-maximal, (4) E is outcome-monotonic, and (5) E is superadditive.

Theorem 1 *An effectivity function $E : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ is the α-effectivity function of a strategic game $G = (N, \{\Sigma_i | i \in N\}, o, S)$ iff E is playable.*

The result can be extended to tight strategic games as follows:

Theorem 2 *An effectivity function $E : \mathcal{P}(N) \to \mathcal{P}(\mathcal{P}(S))$ is the α-effectivity function of a tight strategic game $G = (N, \{\Sigma_i | i \in N\}, o, S)$ iff E is playable and maximal.*

3 Syntax and Semantics of Coalition Logic

Given a finite set of agents/players N, we define the syntax of Coalition Logic as follows. Given a set of atomic propositions Φ_0, a formula φ can have the following syntactic form:

$$\varphi := \quad \bot \mid p \mid \neg\varphi \mid \varphi \vee \varphi \mid \langle C \rangle \varphi$$

where $p \in \Phi_0$ and $C \subseteq N$. We define $\top$, $\wedge$, $\rightarrow$ and $\leftrightarrow$ as usual.

A *coalition model* is a triple $\mathcal{M} = (S, E, V)$ where S is a nonempty set of states (the universe), $V : \Phi_0 \rightarrow \mathcal{P}(S)$ is the usual valuation function for the propositional letters, and

$$E : S \rightarrow (\mathcal{P}(N) \rightarrow \mathcal{P}(\mathcal{P}(S)))$$

is the *global effectivity structure* of the model: For every state $s \in S$, $E(s)$ is an effectivity function. For easier readability, we shall write sE_CX instead of $X \in E(s)(C)$ to denote that C is effective for X at state s. Call a model $\mathcal{M} = (S, E, V)$ *playable* iff for all $s \in S$, $E(s)$ is playable.

It should be clear from the preceding section that we are only interested in playable coalition models, since for these models theorem 1 guarantees that $E(s)$ is the α-effectivity function of a strategic game. So for playable models, every state s is associated with a strategic game $G(s)$, and sE_CX holds iff coalition C is α-effective for X in $G(s)$. Hence, playable coalition models are precisely the kind of action models we were after, since we can see them as concise versions of the generalized action models we described in the introduction.

Given such a model, truth of a formula in a model at a state is defined as follows

$$\begin{array}{ll}
\mathcal{M}, s \not\models \bot & \\
\mathcal{M}, s \models p & \text{iff } p \in \Phi_0 \text{ and } s \in V(p) \\
\mathcal{M}, s \models \neg\varphi & \text{iff } \mathcal{M}, s \not\models \varphi \\
\mathcal{M}, s \models \varphi \vee \psi & \text{iff } \mathcal{M}, s \models \varphi \text{ or } \mathcal{M}, s \models \psi \\
\mathcal{M}, s \models \langle C \rangle \varphi & \text{iff } sE_C\varphi^{\mathcal{M}}
\end{array}$$

where $\varphi^{\mathcal{M}} = \{s \in S | \mathcal{M}, s \models \varphi\}$. Hence, a formula $\langle C \rangle \varphi$ holds at a state s iff coalition C is α-effective for $\varphi^{\mathcal{M}}$ in $G(s)$.

Possibility and necessity can be recovered as extreme cases of effectivity: φ is possible if some play of the game results in a state where φ holds, and φ is necessary if all plays of the game lead to φ. In terms of coalitional power, the possibility of φ can be expressed by $\langle N \rangle \varphi$ whereas the necessity of φ is expressed by $\langle \emptyset \rangle \varphi$.

Note that while we have chosen the $\langle\rangle$ or $\Diamond$ rather than the $[]$ or $\Box$ modality to represent α-effectivity, we might have chosen $\Box$ just as well. One can see from the definition of α-effectivity in section 2 that this notion involves a $\exists\forall$ quantifier combination, and this fact is mirrored in our informal translation of $\langle C \rangle \varphi$ as "coalition C *can force* φ". This hybrid character of the effectivity modality also emerges when inspecting the valid principles of Coalition Logic.

Thanks to theorem 1, we are able to represent coalition models without referring to games and strategies. This simplifies the meta-theoretic treatment of our logic, and it also demonstrates that a coalition model is simply a multi-modal generalization of a neighborhood model (or minimal model, see [4]), providing a neighborhood relation for every coalition of players. Neighborhood models have

been the standard semantic tool to investigate non-normal modal logics, and techniques used to provide complete axiomatization for such logics can also be adapted to Coalition Logic.

4 Conclusions and Applications

Proposing a model of action where the agents' actions jointly determine the new state of the world, we have introduced a logic for talking about what coalitions of agents can bring about. To do this, we made use of concepts and results from game theory and social choice theory on the one hand (strategic games and effectivity functions) and modal logic on the other hand (non-normal modal logic, neighborhood semantics). Theorem 1 can be seen as the central link between these two domains.

Theorem 1 contains the main technical contribution, an extension of the characterization result obtained in [6, 8] to a more general notion of a strategic game which was needed for our dynamic model of actions. More generally, the contribution to game theory and social choice theory has been to place strategic games and effectivity functions into a *dynamic* framework and to introduce a simple formal language to reason about them. On behalf of modal logic, we have shown how non-normal multi-modal logic and neighborhood semantics can be used to describe strategic games and the capabilities of coalitions in such games. The modal operator associated with α-effectivity emerges somewhere in between possibility and necessity.

To conclude, let us mention three areas of possible application for the logic and the model of action we have presented. First, one can think of the players involved as nondeterministic processes which are executed in parallel. The resulting state of the system is determined by the transitions of the individual processes. Viewed in this light, the outcome function in a strategic game can be seen as some kind of communication function as studied in process algebra [2]. In our framework, the result of the communication (the simultaneous actions of the players/processes) is always defined, so communication always takes place and results in a new state.

Second, let us get back to the example given in the introduction. With the apparatus introduced in the previous section, it is easy to provide a coalition model capturing the situation described: With the initial state s_0, we associate a 6-player strategic game where players 2, 3 and 4 can choose between a and b and all other players only have one action available. If the majority of $\{2, 3, 4\}$ chooses a, the outcome state will be s_1, otherwise it will be s_2. At these states, another 6-player game can be played, leading to s_a or s_q in the case of s_1, and to s_b or s_q in the case of s_2, based on the majority of votes. Given the proposition letters a, b and q with the obvious interpretation where for any $x \in \{a, b, q\}$, x is true at s iff $s = s_x$, it can be checked e.g. that in such a coalition model, $\langle\{1,2,3\}\rangle\langle\{1,2,3\}\rangle a$ holds at s_0 while $\langle\{1,4,5\}\rangle\langle\{1,4,5\}\rangle a$ and $\langle\{4,5,6\}\rangle\langle\{4,5,6\}\rangle q$ do not. The other assertions made in the introduction can be verified similarly. In general, this example demonstrates that voting procedures as studied in social choice theory provide a possible field of application. Making a choice from a set of possible alternatives is often done in stages, according to a given agenda. At each stage, the voters make a choice from a number of alternatives, determining a new state of the voting process. Thus,

a sequence of strategic games is played, and the power of certain coalitions of voters can be expressed by formulas of the logic we described.

Third and more generally, the coalition models introduced provide a general model for repeated games [3, 7]. It is easy e.g. to specify a model in which two players are engaged in multiple plays of the prisoners' dilemma. It is unclear however in how far the language provided by the present framework is able to express interesting properties of such repeated games. Nonetheless, Coalition Logic should be viewed as a basis for a possibly richer logic, e.g. one which can express facts about the players' preferences as well.

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Questioning to resolve decision problems

Robert van Rooy[1]
ILLC/University of Amsterdam

1 Introduction

Why do we ask questions? Because we want to have some information. But why this particular kind of information? Because only information of this particular kind is helpful to resolve the *decision problem* that the agent faces. In this paper I argue that questions are asked because their answers help to resolve the questioner's decision problem. By relating questions to decision problems I show (i) how we can measure the utility of questions, and (ii) how these utilities can be used to determine what is actually expressed by agents with their use of interrogative sentences.

2 Utility of Questions

In Savage's (1954) classical formulation of Bayesian decision theory, a distinction is made between states of the world, acts, and consequences; states of the world together with acts determine the consequences, each act-world pair has exactly one consequence, and the consequence of an act include all features that are relevant to the decision maker's values. If we assume that the utility of doing action a in world w is $U(w,a)$, we can say that the *expected utility* of action a, $EU(a)$, with respect to probability function P is

$$EU(a) \quad = \quad \sum_w P(w) \times U(w,a).$$

Let us now assume that the agent faces a *decision problem*, i.e. he wonders which of the alternative actions in A he should choose. A decision problem of an agent can be modeled as a triple, $\langle P, U, A\rangle$, containing (i) the agents probability function, P, (ii) his utility function, U, and (iii) the alternative actions he considers, A. You might wonder why we call this a decision *problem*; should the agent not simply choose the action with the greatest expected utility? Yes, he should, if he *chooses now*. We might say that the *value* of choosing now, i.e. the value of making an *uninformed* decision, is the expected value of the act with the greatest expected utility (where i varies over the actions in A):

$$U(\text{Choose now}) \quad = \quad max_i EU(a_i) \quad = \quad max_i \sum_w P(w) \times U(w,a_i)$$

But now suppose that the agent doesn't have to choose now, but can try to receive some useful information by first *asking a question.* Suppose that the other participant of the dialogue answers this question by giving answer C, and that, as a good Bayesian, the agent himself updates, and knows he will update, his probability state by conditionalizing on C. Then we can say that the value of making an informed decision conditional on learning C is the expected utility conditional on C of the act that has highest expected utility:

$$U(\text{Learn C, choose later}) \quad = \quad max_i \sum_w P(w/C) \times U(w,a_i)$$

This value, which might be smaller than $U(\text{Choose now})$, is always dependent on a decision problem. In this paper we want to use the above mentioned utilities to

[1]Thanks to Maria Aloni and Peter van Emde Boas for helpful comments.

determine the *utility of a question*. But here we face a problem, because even if we assume that the questioner will accept the given answer, the questioner doesn't know which answer this other participant will give. It turns out, fortunately, that we can determine the utility of a question easily when we assume that a question *partitions* the state space (the set of worlds). First, we can determine the value of an *informed decision*; this value is the present expectation of expected value of the choice made after learning the answer (where k varies over the alternative answers):

$$U(\text{Learn answer, choose later}) \quad = \quad \sum_k P(C_k) \times max_i \sum_w P(w/C_k) \times U(w, a_i)$$

Let us now assume that learning via questioning is *cost free*, which means that (i) learning the answer does not affect the set of actions between which the agent can choose, and (ii) the consequences (and thus values) of the actions are known to be independent of the question asked. On the basis of this assumption it can be shown that the value of an informed decision, our U(Learn answer, choose later), is always at least as great as the value of an uninformed decision, our U(Choose now).[2]

This result shows that asking a cost-free question can never do any harm; if you are fronted with a decision problem with alternative actions A, you might as well consider the *sequential* decision problem where you first wonder which (if any) question you should ask, and only then decide which action of A to take. But which question, then, should you ask at the first step? Given the difference between the values of *informed* and *uninformed* decisions, we can now determine a measure that helps to solve this problem: the *value of a question*. This value, utility, or relevance, of a question, given a decision problem, can be defined as the difference between the two above mentioned values:[3]

$$U(Question) \quad = \quad U(\text{Learn answer, choose later}) \; - \; U(\text{Choose now})$$

So, if you wonder which question you should ask in our above described sequential decision problem, the answer seems obvious; the question that would help you most to solve the original decision problem, i.e. the question with the highest utility.

3 Decision problem as contextual parameter

Pragmatics can be seen as the study of the interaction between context and utterance. A context should represent enough information to be able to determine both *what* is said (or meant) by an utterance, and whether it was used *appropriately*. I will argue that the decision problem of the agent who asks a question will be the crucial contextual parameter that helps to determine both (i) what it takes for an assertion to resolve the question, and (ii) whether the interrogative sentence was used appropriately, i.e. whether the question was relevant in its context of interpretation. Just like for other contextual parameters, also the interaction between decision problem (i.e. the relevant contextual parameter) and interrogative used might go in two directions. If you don't know the decision problem, i.e. the *intentions* of the speaker, you might learn something (by *accommodation*) about it from the interrogative sentence used. For linguistic applications of our framework, however, we will concentrate ourselves in this paper on the other side of the interaction. If you *do* know the relevant decision problem of the questioner, you typically will be able to find out what it takes to resolve a question.

[2] Skyrms (1990) traces this result back all the way to some unpublished work of Ramsey.

[3] Decision theorists interesting in the philosophy of science determine in similar ways the value of doing an experiment. Their crucial assumption, however, is that the possible results of the experiment are mutually disjoint. This latter assumption shows that we can use their result if we assume a partition-based analysis of questions, as indeed proposed by Szaniawski (1973).

The analysis of the previous section to determine the utility of questions was based on the assumption that questions should be represented as *partitions*. This reminds us, semanticists, of course immediately to Groenendijk & Stokhof's (1984) analysis of interrogative sentences. Assuming that the meaning of an interrogative is the set of possible (complete) answers to the question expressed, they argue that the possible (complete) answers to not only *yes/no*-questions, but also to *wh*-questions are *exhaustive*, and thus mutually disjoint. If $[[A]](w, g)$ denotes the truth value of A with respect to w and g, the meaning of the interrogative represented by $?\vec{x}A$ is defined as the partition $\{\{v \in W | \, \forall \vec{d} \in D^n : \; [[A]](v, g[^{\vec{x}}/_{\vec{d}}]) = [[A]](w, g[^{\vec{x}}/_{\vec{d}}]) \} | \, w \in W\}$, where $\vec{e}$ is an n-ary sequence.

Groenendijk & Stokhof argue that you only resolve, or completely answer a *wh*-question, when you answer by giving the *exhaustive* list of individuals *by name* who satisfy the relevant predicate. Ginzburg (1995) has recently argued, however, that the notion of *resolvedness* is sensitive to the *goals* of the questioner. In this paper I want to show how a similar idea can be made precise; the idea that whether an answer of a *wh*-question resolves the issue or not depends on the relevant *decision problem* the questioner faces.

I will discuss two ways in which decision problems might be used as crucial contextual parameters. According to the first proposal, we stick to the original *context-independent* partition semantics of Groenendijk & Stokhof, and seek to account for the problems of/counterexamples for their proposal as discussed by Ginzburg by saying that with respect to a certain decision problem an assertion can resolve a question, although it is not a complete semantic answer to it. According to this proposal, a *wh*-question is typically semantically *unambiguous*, but only the notion of *resolvedness* depends on context. The second, and preferred, proposal, on the other hand, assumes that the meaning of a *wh*-interrogative is quite underspecified, or ambiguous, and that the *decision problem* is the crucial contextual parameter to *disambiguate*; the meaning of an interrogative is then the set of answers that would resolve the question with respect to the relevant decision problem.

3.1 Questions precise, resolvedness context-dependent

We have assumed that a decision problem partly consists of a set of alternative actions, and that each action a has a utility in a world w, $U(w, a)$. Let us now assume that the set of alternative actions, A, is such that for each world w there is always exactly one action $a \in A$ such that $\forall b \in (A - \{a\}) : \; U(w, a) > U(w, b)$. This means that the set of alternative actions partitions the set of worlds; to each action $a \in A$ there corresponds a cell of the partition, and in each world of this cell a is the unique best action to do. We will denote this partition by A, too.

Let us assume that the agent is considering the alternative actions in A, which question should he ask? The best thing to do, obviously, is to ask that question that gives rise to the same partition as A does; this is the question that according to section 2 has the highest value. This is obviously better (neglecting strategic deliberations) than to ask a question that gives rise to a partition that is *orthogonal* to the partition induced by A, or when this latter partition is a *refinement* of the partition induced by the question, where partition P is a refinement of Q iff $\forall X \in P : \; \exists Y \in Q : \; X \subseteq Y$. What about questions that give rise to partitions that are refinements of A? The natural thing to say, it seems, is that these questions can be as useful (although at the 'cost' of asking something too specific) as the question equivalent to A, but that to resolve the question, the answer does not have to be equally fine-grained as the question itself seems to demand. It only has to be so fine-grained to resolve the decision problem, i.e. as fine-grained as A.

Suppose, for example, that you ask me *Where do you live?* Ginzburg rightly argues that depending on your goal, in some contexts this question might be resolved

by an answer like *In Amsterdam*, while in other contexts I should give a more specific, or fine-grained, answer and say something like *In Amsterdam East*. Let us now assume that the context-independent semantic analysis of questions assumes a level of fine-grainedness related to the second kind of answer. If we now think of the first kind of answer in terms of the fine-grainedness of the second, we might think of the first answer as a disjunction of several (East or West or ...) answers of the second kind. Then we can say that the decision problem determines how *fine-grained* the answer should be to resolve the question. Thus, if $\{d, d', e, e'\}$ is the set of places relevant at the most fine-grained level, we might say that a question like *Where do you live?* gives *semantically* always rise to the following partition:

$$\begin{aligned} Q \quad = \quad & \{\{w \in W \mid \text{I live in } d \text{ in } w\}, \ \{w' \in W \mid \text{I live in } d' \text{ in } w'\}, \\ & \{v \in W \mid \text{I live in } e \text{ in } v\}, \ \{v' \in W \mid \text{I live in } e' \text{ in } v'\}\} \end{aligned}$$

Now suppose that d and d', and e and e' denote the east and west of Amsterdam and Utrecht, respectively. If the decision problem, A, is such that the questioner knows what to do when he knows that he is in Amsterdam, and something similar for Utrecht, the distinctions between d vs. d', and e vs. e' become irrelevant; although the answer *In Amsterdam* wouldn't count as a complete semantic answer, it still would resolve the relevant decision problem. That is, each element of the following more coarse-grained partition would resolve the answer:

$$Q_A \quad = \quad \{\{w \in W \mid \text{I live in } d \text{ or } d' \text{ in } w\}, \ \{v \in W \mid \text{I live in } e \text{ or } e' \text{ in } v\}\}$$

Although such an analysis might be natural for some cases where the appropriateness of an answer is context-dependent, it only seems to work when *fine-grainedness* is at stake.[4] But the dependence on context, i.e. the decision problem, can be of a different nature, too. Groenendijk & Stokhof (1984) argue, for instance, that a question like *Where can I buy an Italian newspaper?* can, depending on context, be answered appropriately in two ways; one of which is just by mentioning one positive instance. Intuitively, this context-dependency has something to do with the alternative actions the questioner considers. But it is not easy to see how the notion of 'fine-grainedness' can play the crucial role (by turning the default mention-all interpretation of the question into the mention-some interpretation). Something similar holds for *identification*-questions like *Who is Wim Kok?* It seems natural to say that depending on the decision problem this question should sometimes be answered by giving a referentially used expression (I want to shake hands with d, if d is Wim Kok, and with e, if e is Wim Kok, but I don't know who is), and at other times by a descriptively used one (I only want to listen to your story about the individual you call 'Wim Kok', if he is an interesting person). But it is completely unclear how to account for this intuition if it is assumed that questions are semantically *unambiguous*, and that decision problems can only influence the fine-grainedness of the required answers.

3.2 Questions underspecified, disambiguation by context

Groenendijk & Stokhof argue that *wh*-questions are in general semantically ambiguous between their mention-all and mention-some interpretation. As already suggested above, the assertions that would resolve, or answer, the question then typically depend on the decision problem the questioner faces. Thus, the semantic meaning of an interrogative is ambiguous, or underspecified, and the decision problem helps to *disambiguate*, the hearer chooses that interpretation that would

[4]There is another problem for this proposal: it is based on the strong assumption that at each world there is a unique best action to do relevant to the decision problem.

be the most *rational*, or *useful*, with respect to this known decision problem.[5] But if this is the way to look at the semantics/pragmatics interface with respect to the mention-some vs. mention-all readings of interrogatives, why not assume that decision problems play a similar role for other cases where the resolvedness, or better *meaning*, of questions is context-dependent? The most obvious way in which a *wh*-interrogative might be said to be ambiguous is due to the fact that the *domain* over which the *wh*-phrases range is *context-dependent*. This context-dependence is normally (e.g. Van Rooy (1997), Aloni (ms)) accounted for by assuming that the relevant domain for each question is simply anaphorically given as a separate feature of the context. In this paper I want to go one step further, and thus give a more *explanatory* analysis of this context-dependence; select the relevant domain by means of the decision problem at stake.[6]

When I ask *Who will go to the concert?*, for example, I only have a restricted set of individuals in mind that I care about; my own actions only depend on what these few individuals will do. When the hearer knows this, he can conclude that the *wh*-phrase only ranges over this limited set of individuals. More abstractly, the question asked by the interrogative represented by $?xPx$ depends on the subdomain of individuals in D over which variable x ranges. But this subdomain, in turn, can be selected by the decision problem; individual d is not an element of this subdomain if learning that d is a P is *irrelevant* for the decision problem, i.e. if learning $P\mathbf{d}$ neither results in choosing a different action, nor changes the height of $max_i EU(a_i)$, i.e. $U(\text{Learn } P\mathbf{d}, \text{ choose later}) = U(\text{Choose now})$, where $\mathbf{d}$ refers to d.

In the above example the decision problem was used to select the relevant subdomain of our 'original' D that functions as domain of 'quantification'. But as the example discussed in the previous subsection suggested, these domains need not be subdomains of D, they can also be thought of as sets of more *coarse-grained* objects. Thus, to select the relevant domain, we should not only consider the *size*, but also the *fine-grainedness* of the objects.[7] Also the level of fine-grainedness depends on the decision problem; if we see each other in Germany, and you consider visiting me or not, it would be useless to answer your question *Where do you live?* by saying *In Europe*, while I presumably also need not give my precise address. In abstract, the selected level of precision will be the least one of those levels for which the value of the question asked would be maximal.

Except for the fine-grainedness and size, it has recently been argued by Gerbrandy (1997) and Aloni (ms) that for so-called *identification*-questions the relevant domain of 'quantification' also depends on the *method of identification*. If I ask *Who is Cassius Clay?* it depends on context whether you can answer this question by pointing to a certian individual, give his other name (*Muhammed Ali*),[8] say something like *The heavy weight champion of boxing in the seventies*, or use the description he used himself, i.e. *The Greatest*. Thus, depending on context there might be different ways to conceptualize, or identify, the relevant individuals. Gerbrandy and Aloni argue that to account for this, we should assume that the domain over which a *wh*-phrase ranges is a set of *individual concepts*,[9] and that the

[5]Notice that in principle there is no problem to give a partition-based analysis of mention-some questions; we simply assume that possibilites might be finer-grained than worlds.

[6]See Merin (1997) for a related decision-theoretic approach to select the elements of a scale relevant to determine scalar implicatures.

[7]Not any set of coarse-grained objects will do to figure as domain of quantification, obviously; a set of 'vague' objects can only come into question when there is no mutual overlap between the precisifications of its elements, i.e. we should be able to think of the set as a partition of the most fine-grained domain D.

[8]It is obvious that when both proper names and demonstratives are treated as rigid designators, both answers are wrongly predicted to be always uninformative.

[9]Just as before, some sets of concepts are never allowed; it is not allowed that there are worlds in which two concepts of the relevant domain of quantification overlap, i.e. have the same denotation.

relevant set of individual concepts depends on the method of identification. The meaning of the interrogative sentence itself is highly underdetermined, because it depends very much on the contextually given method of identification. Gerbrandy and Aloni assume that the relevant method is just given, but once we assume a decision problem as a relevant contextual parameter, something more can be said. Just as before, the domain over which the *wh*-phrase of an interrogative ranges is the one for which the resulting question would have the highest utility.

4 Conclusion and outlook

In this paper I have shown that by relating questions to decision problems, we can determine the utility of (unambiguous) questions in a natural way. Moreover, I have argued that this measure is relevant for linguistic applications, because it might help to determine the actual question expressed by an interrogative sentence. I think this is yet one more argument for the claim that what is actually *said* (and not just *meant*) by a sentence crucially depends on the attitudes of the participants of the conversation.

In this paper I have made two non-trivial assumptions; (i) asking a question is always *cost-free*, in particular, the questioner doesn't mind to make his intentions fully explicit and never tries to hide them, and (ii) the respondent will always answer the question by giving the *complete* answer; it is assumed that the respondent is fully informed and fully *cooperative*. In daily life, however, these assumptions cannot always be made; agents do not always want to 'give away' as much information as they should according to the analysis used in this paper. It remains to be seen in how far we can extend our analysis when we give up these assumptions.

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Towards a Semantic-based Theory of Language Learning

Isabelle Tellier
Laboratoire d'Informatique Fondamentale de Lille, équipe Grappa

Abstract

The notion of Structural Example has recently emerged in the domain of grammatical inference. It allows to solve the old difficult problem of learning a grammar from positive examples but seems to be a very *had hoc* structure for this purpose. In this article, we first propose a formal version of the Principle of Compositionality based on Structural Examples. We then give a sufficient condition under which the Structural Examples used in grammatical inference can be inferred from sentences and their semantic representations, which are supposed to be naturally available in the environment of children learning their mother tongue. Structural Examples thus appear as an interesting intermediate representation between syntax and semantics. This leads us to a new formal model of language learning where semantic information play a crucial role.

1. Introduction

The problem of grammatical inference from positive examples consists in the design of algorithms able to identify a formal grammar from sentences it generates. It is the computational version of the problem of children language learning and is then of great cognitive interest.

But strings of words are not informative enough to specify a grammar : it has been proved that even the class of regular languages is not learnable from positive examples in usual models of learning ([4, 14]).

To overcome this difficulty, a recently investigated solution consists in providing *Structural Examples* to the learner instead of strings of words ([2, 6, 7, 10, 11]). A Structural Example is a more or less simplified version of the syntactic (or analysis) tree.

But this solution is not very satisfying from a cognitive point of view, as Structural Examples seem to be very unnatural species. The purpose of this article is to provide a new interpretation of Structural Examples, as a relevant intermediate level between syntax and semantics. This interpretation allows to formulate a simple rule-based definition of the Principle of Compositionality and a semantic-based model of natural language learning.

2. Structural Examples used in Grammatical Inference

Let us call a *composition* a tree whose leaves are taken among a finite vocabulary Σ and whose internal nodes are indexed by symbols belonging to a signature Γ. In the following, we will note $\Gamma=\{g_1, \ldots, g_m\}$, for some integer m.

For any (context-free) grammar G, let us partition the set of rules of G and associate a unique symbol taken among Γ with each class. A composition built on the vocabulary Σ of G is said to be a *Structural Example for G* iff there exists a syntactic tree generating the corresponding sentence in G so that the composition is obtained by replacing every non terminal symbol of this syntactic tree by the symbol class of the rule used to rewrite it.

Example 1 :

It is well know ([1]) that AB-Categorial Grammars are equivalent with context-free grammars, so the previous definitions can straightforwardly be adapted to this class. Let us define a basic AB-Categorial Grammar G' for the analysis of a small subset of English. Let Σ'={a, man, John, Mary, runs, loves} be the vocabulary and {S, T, CN} the set of basic categories. In this set, S is the axiom, T stands for "term" and CN for "common nouns". The assignment function f is then defined by : f(John)=f(Mary)={T}, f(runs)={T\S}, f(loves)={(T\S)/T}, f(man)={CN} and f(a)={(S/(T\S))/CN}.

The only admitted reduction rules, as usual, are called R1 and R'1 and are defined by : for any category A and B, R1[A/B, B]=A and R'1[B, B\A]=A.

This grammar allows to recognize sentences like : "John runs", "a man runs" or "John loves Mary" as follows (with a little abuse of notation, for readability, rules R1 and R'1 are used as if they applied on couples (word, category) instead of on categories alone) :

R'1[(John, T).(runs, T\S)]=(John . runs, S)

R1[R1[(a, (S/(T\S))/CN).(man, CN)].(runs, T\S)]
=R1[(a . man, S/(T\S)).(runs, T\S)]=(a . man . runs, S)

R'1[(John, T).R1[(loves,(T\S)/T).(Mary, T)]]
=R'1[(John, T).(loves . Mary, T\S)]=(John . loves . Mary, S)

Let Γ'={g_1, g_2}. In AB-Categorial Grammars, the most natural partitioning of the set of rules is based on the distinction between the two directions of functional application : let then R1 be indexed by g_1 and R'1 by g_2. The Structural Examples for our grammar corresponding with the previous three analysis trees are then respectively : g_2(John, runs), $g_1(g_1$(a, man)), runs) and g_2(John, g_1(loves, Mary))

When Γ is reduced to a unique symbol, Structural Examples only display the branching of the syntactic trees without indication about the intermediate non terminal symbols, and are called *skeletons*.

The problem of grammatical inference from Structural Examples consists in identifying a formal grammar from Structural Examples. It has been recently studied and partly solved when the set of rules is partitioned into one class (i. e. with skeletons) in [10, 11] or, like in the example, into two classes for Classical Categorial Grammars (or AB-Categorial Grammars) in [2, 6, 7].

Some of the algorithms providing a solution to this new problem are computationally efficient. But, when provided with sentences, trying every possible composition based on these sentences is computationally highly expensive in space and time and the result is a set of many compositions among which the Structural Example(s) is(are) indistinguishable.

3. The Principle of Compositionality

Since Montague's work ([8]), the Principle of Compositionality is often formally stated as a rule-based correspondence between syntactic and semantic trees ([5]). The interesting point to notice is that this correspondence between *rules* is independent of the nature of the intermediate non terminal symbols (or categories) appearing at the nodes of the syntactic tree. This means that the full syntactic tree is not necessary to obtain the semantic tree : the corresponding Structural Example is enough, *provided that the partition of the syntactic rules made to define it coincide with the distinct useful semantic functions.*

To formalize this idea, let a Compositional Set <G, Γ, K, H> be composed of a (context-free) grammar G, a signature Γ, a mapping K associating each rule of G with a symbol of Γ (defining the partition of the set of rules of G) and a compositional meaning assignment H=<L, t, T> defined as follows :

- L is a semantic representation language ;
- t is a mapping associating each member of the vocabulary Σ of G with a unique meaning in L : as, in Structural Examples, we give up the categories of the analysis tree, t *only depends on the vocabulary*, so we have to admit here a non ambiguous meaning assignment for words ;
- T is a *bijective* mapping associating each symbol g_j in Γ with a semantic function noted h_j, $1 \le j \le m$.

H is a morphism applying on *compositions*. For any sentence $w=u_1...u_n$ generated by G and any composition on w noted g*(w), H is defined by : $H[g^*(u_1...u_n)]=T(g^*)[t(u_1)...t(u_n)]$, obtained from $g^*(u_1...u_n)$ by replacing each u_i by $t(u_i)$, $1 \le i \le n$ and each g_j by $T(g_j)=h_j$, $1 \le j \le m$. For every *Structural Example* g*(w), *the evaluation of the expression H(g*(w)) represents the (or, in case of syntactic ambiguity, one of the) meaning(s) of w.*

Example 2 :

Let <G', Γ', K', H'> be a Compositional Set assigning meaning representations to the sentences generated by the grammar G' of Example 1. K' associates R1 and R'1 respectively with g_1 and g_2 and H'=<L', t', T'>. For sake of simplicity, L' is a typed (the typing system cannot be developed here) first order predicate logic augmented with lambda-calculus (i.e. an unintensional version of Montague's intensional logic). Furthermore :

- t' associates each word u in Σ with a logical formula t'(u) in L' (respecting the types). The logical translations of individual words are :
  * $t'(a)=\lambda P_1 \lambda Q_1 \exists x[P_1(x) \wedge Q_1(x)]$

where x and y are individual variables and P_1 and Q_1 variable predicates of arity 1 (as indicated by the indexes).

* every other word u in Σ is translated into a logical constant noted $t'(u)=u_i$' where i is the arity, only noted when $i \ge 1$ (conjugated verbs are first reduced to their infinitive form).

- T' is defined by :
  * $T'(g_1)=h_1$ where for every couple (a, b) in L', $h_1(a, b)=a(b)$;
  * $T'(g_2)=h_2$ where for every couple (a, b) in L', $h_2(a, b)=b(a)$;

The application of H' to the Structural Examples of Example 1 gives :

$H'[g_2(John, runs)]=T'(g_2)[t'(John), t'(runs)]$
$=h_2[John', run_1']=run_1'(John')$

$H'[g_1(g_1(a, man)), runs)]=T'(g_1)[(T'(g_1)[t'(a), t'(man)]), t'(runs)]$
$=h_1[h_1(\lambda P_1\lambda Q_1\exists x[P_1(x)\wedge Q_1(x)], man_1'), run_1']$
$=(\lambda P_1\lambda Q_1\exists x[P_1(x)\wedge Q_1(x)](man_1'))(run_1')$
$=\exists x[man_1'(x)\wedge run_1'(x)]$

$H'[g_2(John,g_1(loves, Mary))]=T'(g_2)[t'(John),T'(g_1)[t'(loves),t'(Mary)]]$
$=h_2[John', h_1(love_2', Mary')]$
$=love_2'(Mary')(John')$.

Note that skeletons may not be precise enough to specify compositional semantics because as $\Gamma=\{g_1\}$, only one semantic function $T(g_1)=h_1$ is allowed. But, in the vast domain of computational linguistics, compositional logical-based meaning are classical and extensions of the basic version of Example 2 -to Lambek grammars for instance ([12])- can be defined. In some cases, the Curry-Howard correspondence specifies the mapping T.

Structural Examples can thus be considered as the *minimal basis necessary for the definition of compositional semantics*. This link between Structural Examples and semantics can now help us interpreting where Structural Examples come from in the learning domain.

4. A new learning model

It is natural to suppose that when a child learns a language, she has at her disposal (heard) syntactically correct sentences together with their *meaning*, available in the environment (and pointed by the speaker). The corresponding computational situation is an algorithm which takes as input both syntactically correct sentences and (one of) their semantic representation(s).

Let us suppose that the underlying linguistic system is a Compositional Set <G, Γ, K, H> where H=<L, t, T> and that the innate knowledge includes the semantic language L, the set $\Gamma=\{g_j\}_{1\leq j\leq m}$ and the corresponding set of semantic functions $\{h_j\}_{1\leq j\leq m}$. The rule translation mapping T is then considered as universal and independent of the language to be learned. As in usual semantic-based methods of learning ([3]), word meanings (i.e. the mapping t) are also supposed to be already known when the grammatical inference starts. Only G and K remain to be learned.

But to make use of the input data, we need more than the Principle of Compositionality : we need a property that we suggest to call *Fully Compositionality*. A Compositional Set <G, Γ, K, H> will be said *Fully Compositional* if for every sentence w generated (or recognized) by G and every *composition* g*(w) built on w, we have : if there exists a Structural Example g'*(w) for G satisfying : eval(H(g*(w)))=eval(H(g'*(w))) then g*(w) is also a Structural Example.

To help intuition, this new definition can be considered as stating that if w is a syntactically correct sentence then any composition based on w and translated by H into a correct meaning for w (i.e. any compositionally-

obtained meaning) is also a Structural Example for G. In other words, in a Fully Compositional framework, the evaluation of the image by H of a composition can be used as a *criterion* for deciding if this composition is in fact a Structural Example.

In this case, from input couples made of a sentence and (one of) its meaning(s), it is possible to infer Structural Examples. Figure 3 shows two strategies for this, called *forward* and *backward inference* because of their similarity with usual forward and backward chaining in deduction theory.

for any <w, m> where $w=u_1...u_n$ is a sentence and m (one of) its meaning representation(s) do :
- *found <- false ;*
- *while NOT (found) do*
  - ** try a composition e=g*(w) based on w ;*
  - ** if eval(H(e))=m then found <-true ;*
- *return(e).*

for any <w, m> where $w=u_1...u_n$ is a sentence and m (one of) its meaning representation(s) do :
- *found <- false ;*
- *while NOT (found) do :*
  - ** try a composition on the semantic translations : $k=h^*(t(u_1)...t(u_n))$;*
  - ** if eval(k)=m then found <- true ;*
- *return($(T^{-1}(h))^*(w)$)*

Figure 3 : forward and backward inference of Structural Examples

Both algorithms are *in the worst case* exponential in time but only *linear in space*, since only one candidate Structural Example is stored and checked at the same time. The total number of different possible compositions g*(w) defined from a signature $\Gamma=\{g_j\}_{1\leq j\leq m}$ where each g_j is of arity 2 based on a sentence $w=u_1...u_n$ composed of n words with $n\geq 1$ equals : $C(n-1)*m^{n-1}$ where C(k) is the Catalan number defined by $C(k)=(2k)!/(k!(k+1)!)$ for any $k\in\mathbb{N}$ (the Catalan number C(k) counts the number of binary trees with k internal nodes, that is with k+1 leaves).

But much better efficiency can be obtained by taking into account the *arities* of word meanings in the backward inference algorithm, as follows.

Example 3 :

A natural simple heuristic is the following : "when trying a composition on a sequence of semantic expressions, first try the functional applications between two logical expressions whose arities are in decreasing order". Let us apply it to our examples sentences :

- from the sequences of word meanings : "John', run'_1", and "$\lambda P_1\lambda Q_1\exists x[P_1(x)\wedge Q_1(x)]$, man_1', run_1''", the only semantic compositions respecting the heuristic are the only ones which are also Structural Examples.
- from the sequence : "John', $love_2'$, Mary'", the heuristic selects two semantic compositions among eight possible, including the correct one.

5. Interpretation

The learning strategy for natural languages proposed here applies in two steps. The first step, where semantic information play a crucial role, is *the*

inference of Structural Examples. Although it remains to be proved, usual compositional syntactico-semantic frameworks seem to satisfy the Fully Compositionality property. In this case, Structural Examples can be inferred from strings of words and semantic representations. The second step is the *inference of a grammar from Structural Examples* which has already received interesting partial solutions. Structural Examples thus appear as a crucial intermediate representation between syntax and semantics.

Note that when the full target is reached, the system applying this strategy will be able not only to parse a syntactically correct sentence with G, but also to associate a meaning with it, which is the exact cognitive definition of *learning to understand* ([13]). This new conception of language learning is a formal alternative to usual purely syntactic theories and it meets the psycholinguistic opinion that : " knowing a language is knowing how to translate mentalese into strings of words and vice-versa " ([9]).

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A Different Game?
Game Theoretical Semantics as a New Paradigm

Louise Vigeant
Department of Linguistics
Stanford University

Hintikka distinguishes two types of language theories: rule-oriented and game-oriented. His examples of rule-oriented language theory are Government and Binding syntactic theory and Montague semantics. The game-oriented viewpoint is best represented by Game Theoretical Semantics. Hintikka believes that Game Theoretical Semantics is different enough from other approaches to constitute a paradigm shift in the study of language (Hintikka, 1990). In this paper, I will look at two interrelated issues. The first is whether Game Theoretical Semantics can be truly considered a drastic move away from a rule-oriented interpretation of language. The second is what condition would need to be fulfilled to constitute a paradigm shift for semantic theory. I agree with Hintikka that the later Wittgenstein does give a radically different view of language. However his contribution was not only to introduce games into the discussion but also to make us reevaluate the connection between truth and language.

In the early seventies Hintikka and his collaborators began developing Game Theoretical Semantics as an alternative semantic theory. It is very clear that this semantic theory is an instantiation of what Hintikka believes to be Wittgenstein's idea of a language game:

> It is here that the language-games of seeking and finding which I have discussed elsewhere and which I gave argued to constitute the logical home of quantifiers are useful also for the purpose of evaluating Wittgenstein...They supply examples of language-games of precisely the sort we expect to find but do not in Wittgenstein.
>
> (Hintikka, 1976:pg. 16)

The games that Hintikka uses to illustrate his conception of Wittgenstein's philosophy are not obvious candidates. The most salient reason for this is that Wittgenstein does not delimit what constitutes a game.

The connection between Wittgenstein and Game Theoretical Semantics can be found in Hintikka's interpretation of his philosophy. In *Investigating Wittgenstein* both Merrill and Jaakko Hintikka provide an interpretation of Wittgenstein which they feel is a departure from the standard explanations of his writings. Specifically, they reject the claim that the main goal of philosophy should be therapy. Rather, they see Wittgenstein's philosophy as an extended theoretical project. The first major change in the thinking of Wittgenstein is a movement away from a phenomenological theory of language to one that is

physicalist. At the base of the theory of language in the *Tractatus* are simple objects. Knowledge of these objects could only be obtained directly from experience which is mediated through our senses – thus the phenomenological description of the philosophy of the *Tractatus*. According to the Hintikkas, what the later Wittgenstein sheds is the view that a 'primary' language was necessary to describe our ordinary language.

This loss of a mediating language between our language and reality also necessitated a shift in Wittgenstein's explanatory strategy (Hintikka and Hintikka, 1986). By having simple objects as the foundation of his earlier theory, Wittgenstein was able to maintain that there was a direct link between object and the object-name. The Hintikkas argue that the actual nature of this relationship is 'ineffable'. The difference in the later Wittgenstein is that the connection we make between language and reality need not be a mystery. It is through the playing of language games that the relation between an object and its name is established and understood.

A language game gives a resting place where discussion of rules as a description of our linguistic abilities makes sense. Language games can be described in terms of their rules but rules can't be discussed without first some reference to the game in which they are found. As a direct reflection of Hintikka's interpretation of Wittgenstein's philosophy, the explanation Game Theoretical Semantic provides for our understanding of language is the connection between language and reality through the games which are described in the theory (Hintikka, 1976). It is in this way that this theory represents a departure from standard semantic theories.

Game Theoretical Semantics analyses language as a game between two players. It is the role of one of the players of the game to verify the sentence, initially the Verifier, and for the other player to falsify the sentence. A sentence is defined as true if the Verifier has a winning strategy for the game. It is this strategic definition of truth that identifies Game Theoretical Semantics as a game-oriented language theory. Hintikka focuses on quantifiers to illustrate his strategic definition of truth. He conceives the language game surrounding quantifiers as a two person game of seeking and finding. The players must seek and find and object that will either falsify or verify the sentence depending on what the rule surrounding the quantifier says and the role that a player has in the game.

Hintikka has asserted that Game Theoretical Semantics is a paradigm shift in language theories. In effect, he is saying that his theory is a revolution in semantics. According to Kuhn, the advent of a paradigm shift is marked by the introduction of a new scientific theory that is able to cover not only the facts of the precursor but certain anomalies that were not explicable in the old theory. Hintikka is quite clear how his theory is able to account for certain linguistic facts that the dominant theory (in his discussion it is Chomskian syntax) is currently unable to explain. I will not address this point.

The more salient issue is whether or not this theory represents a different 'conceptual scheme' than its forebearers. This is the distinction that I think Hintikka is most heavily trading on. Since there is no agreed upon definition, I will use a very broad description of paradigm change:

> The transition from a paradigm in crisis to a new one from which a new tradition of normal science can emerge is far from a cumulative process, one achieved by an articulation or extension of the old paradigm. Rather it is a reconstruction of the field that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications.
>
> (Kuhn, 1962: pg. 85)

I have no method of judging how well Game Theoretical Semantics has managed to reconstruct the field of semantics' generalizations, methods and applications. Instead, I will focus my attention on the question of whether or not Hintikka's theory is an extension of current language theories.

The first major difference between Game Theoretic Semantics and rule-oriented semantic theories is the little emphasis that it places on syntax. Hintikka is especially critical of Chomsky and his Government and Binding theory of syntax (Hintikka, 1990). His attack of Chomskian linguistics is based on his assertion that it is an example par excellence of a rule-oriented language theory. The goal of a syntactic theory is to give all and only the well-formed sentences of a language. This theory is argued by Chomsky to constitute our knowledge of language as is evidenced by his competence/performance distinction. The problems associated with this type of explanation of language are thoroughly explored in Kripke's famous rule-following discussion.

Hintikka however does not seem to be entering into a high level debate about knowledge of language. Rather as with most semantic theories, his interest is with a proper characterization of the link between language and the world. Government and Binding theory quite conceivably falls short on this front but that is not its primary goal. Analogously, a discussion of Game Theoretic Semantics as a syntactic theory is a bit misplaced. Though Hintikka may not have a particularly well developed syntactic component, he is not without syntax. The role of the ordering principle is to control the application of the semantic rules. It is equivalent to a very simple syntax. Whether one has a little or a lot of a syntax in this particular context seems a rather uninteresting question.

The second and more striking difference is that Game Theoretical Semantics does not follow Frege's principle and is non-compositional. The specific problem that is used to illustrate this property of the theory is branching quantifiers. These are logical formula where the quantifiers are independent of each other in the interpretation. Informationally independent quantifier are not in the scope of each other. There is no way to represent this in a purely linear representation

such as would be found in first order logic. Game Theoretical Semantics is equipped to cope with these situations as the movement of the players are independent of each other and it through the choices of the players that the quantifiers are interpreted.

Branching quantifiers are at odds with the principle of compositionality because they can't be interpreted without reference to the context within they appear. The importance of the claim that Game Theoretical Semantics is non-compositional is hard to evaluate because of recent work by both Hodges and Janssen. Hodges presents a semantics for what he calls 'Independence-Friendly' logic. The strategy that a player uses need not be blind. Decisions made by a player earlier in a game can provide input into later choices. Janssen provides what he terms a 'Uniform-Friendly' logic. The choices a player makes are constrained so that whatever decision is made will result in a win. The definition of truth in Game Theoretical Semantics is in terms of strategy and winning strategies can be defined as a set (As). The interpretation of a formula can be given as a set of assignments. If the choice of assignments that the Verifier gives a formula is from As, she is guaranteed a win (Janssen, 1997). Though Hintikka's original conception of this theory may have been non-compositional, work is currently under progress that questions this assumption.

Is a strategic definition of truth enough to consider Game Theoretical Semantics a paradigm shift? The new conceptual scheme that this definition of truth represents is supposed to be a reflection of Wittgenstein and his discussion of language in the *Philosophical Investigations*. It is the use of language games as an explanatory mechanism that is different and new. This appeal to Wittgenstein is a touch risky. It leaves Hintikka open to a Wittgensteinian rebuke of his theory. The wide-ranging use of the word 'game' in the *Investigations* makes it difficult to pin this term to any definitive description of games as Hintikka has sought to do.

As an opening salvo to the much debated section on what it is to follow a rule, Wittgenstein looks at a possible definition of a proposition:

> And to say that a proposition is whatever can be true or false amounts to saying: we call something a proposition when in our language we apply the calculus of truth functions to it.
> (Wittgenstein, 1958: §136).

Now as is often cited in Wittgenstein scholarship, it is irresponsible to pull random sentences out of the *Philosophical Investigations* and build arguments. However, I think the conclusion of this section is quite clear:

> And the use of the words 'true' and 'false' may be among the constituent parts of this game: and if so it belongs to our concept 'proposition' but does not 'fit' it.
> (Wittgenstein, 1958: §136).

A proposition cannot be defined purely in terms of the ability to apply true and false to it.

The building blocks of Game Theoretical Semantics are propositions. It is on these entities that the games are played. But there are no basic assumptions about language games in the *Investigations*. Propositions do not inhabit a privileged position in the thinking of Wittgenstein. That is because the connection between truth and propositions is not an 'ineffable' link. It is as much open to questioning as other tenets in philosophy.

Thus to create a semantic theory based in language games is a fairly complex task. It goes beyond defining a game frame-work in which to evaluate sentences. Game Theoretic Semantics has focused purely on this aspect of the game paradigm. It also involves an evaluation of the building blocks of semantic analysis: propositions. Hintikka has not begun this process.

> The game-theoretical analysis of truth takes the meanings of primitive nonlogical constants of an interpreted first-order language for granted. This fixes the truth-values of the relevant atomic sentences, that is, of all sentences that can serve as endpoints of a semantic game...The fact that I am thus restricting my task does not mean that I consider further model-theoretical analysis of meaning unnecessary. My only reason for the restriction is that otherwise the scope of my enterprise would become unrealistically and unmanageably large.
> (Hintikka, 1995: pg. 233)

At base, Game Theoretic Semantics is treating atomic sentences in exactly the same manner as model theoretic semantics.

Treating the relationship between propositions and truth as primitive is unproblematic for Hintikka because he believes that sentence meaning is 'inextricably' linked to truth (Hintikka, 1995: pg. 233). This is a perfectly defensible view but not obvious is a theory that is supposed to be inspired by Wittgenstein. The 'fit' between propositions and truth is a puzzle that is in need of some attention in Game Theoretic Semantics. More specifically, what is a game inspired definition of a proposition? I see no clear path to the answer of this question. I suspect that Game Theoretical Semantics may be simply too close in kind to its model theoretic brethren. The claim that Game Theoretic Semantics is a new 'paradigm' of semantic theories is premature. At the moment all that it has to distinguish itself is a different definition of truth. Many of the core assumptions of a rule-oriented semantic theory rest undisturbed. Wittgenstein's introduction of the notion of a 'language game' is more far-reaching than Hintikka's use of the notion in Game Theoretical Semantics. The relationship

between propositions and truth is a tangible example of this. It is only in defining this side of games too would Hintikka really have a paradigm shift rooted in Wittgenstein.

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Plural Type Quantification

Yoad Winter
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This paper introduces some of the main components of a novel type theoretical semantics for quantification with plural noun phrases. This theory, unlike previous ones, sticks to the standard generalized quantifier treatment of singular noun phrases and uses only one lifting operator per semantic category (predicate, quantifier and determiner) for quantification with plurals. Following Bennett (1974), plural individuals are treated as functions of type et. Plural nouns and other plural predicates accordingly denote $(et)t$ functions. Such predicates do not match the standard $(et)((et)t)$ type of determiners. Following Partee and Rooth (1983), type mismatches are resolved using *type shifting operators*. These operators derive collectivity with plurals, keeping the analysis of singular noun phrases, where no type mismatch arises, as in Barwise and Cooper (1981). A single type shifting operator for determiners combines into one reading the *existential* shift and the *counting* (neutral) shift of Scha (1981) and Van der Does (1993). This operator combines the *conservativity* principle of generalized quantifier theory with Szabolcsi's (1997) existential quantification over *witness sets*. The unified lift prevents unmotivated ambiguity as well as the monotonicity ill of existential lifts pointed out by Van Benthem (1986).

Bennett's typing of plurals is based on the distinction between *atomic entities* of type e and *sets* of atomic entities characterized by et functions. This distinction is reflected in the *lexical type* of natural language predicates, which are divided into two subclasses:[1]

1. *Atom predicates* of the lexical type et, including intransitive verbs like *sleep, sing* and *dance* and nouns like *student, teacher* and *committee*.[2]

2. *Set predicates* of the lexical type $(et)t$ (abbreviated ett), including intransitive verbs like *meet, gather* and *disperse* and relational nouns like *friend, brother* and *colleague*.

Non-lexical predicates, inflected with number agreement features, may be of a different type than their lexical type according to the following rules of thumb.

1. Morphologically *singular* predicates are of type et, even when their lexical type is ett.

2. Morphologically *plural* predicates may get the ett type, even when their lexical type is et.[3]

For example, the singular nouns *student* and *friend* and the singular verbs *sleeps* and *meets* are of type et. The plural nouns *students* and *friends* and the plural verbs *sleep* and *meet* are of type ett.

This typing is compositionally derived using the following denotations assumed for the (sometimes covert) number features +SG (singular) and +PL (plural). The +SG feature denotes the function that lowers an ett predicate to type et by unioning the singletons in its extension. The +PL

[1] In Winter (1998,1999) I argue that the distinction between atom predicates and set predicates should not be the classical distributive/collective typology of predicates and suggest a new empirical test for the atom/set classification.

[2] According to the criterion mentioned in footnote 1, and following Barker (1992) and Schwarzschild (1996), "group denoting" nouns like *committee* and *senate* have the same semantic type as other simple nouns.

[3] In fact, as will be remarked below, plural predicates are assumed to be ambiguous between types et and ett.

feature denotes the identity function on *ett* predicates. Formally:

$[\![\text{+SG}]\!] = sg_{(ett)(et)} \stackrel{def}{=} \lambda\mathcal{P}_{ett}.\lambda x_e.\mathcal{P}(\{x\})$

$[\![\text{+PL}]\!] = id_{(ett)(ett)} \stackrel{def}{=} \lambda\mathcal{P}_{ett}.\mathcal{P}$

Note that the +SG and +PL number features denote functions whose arguments are of type *ett*. This creates a *type mismatch* with atom predicates, which are lexically of type *et*. Following Partee and Rooth (1983), this type mismatch triggers a process of *type fitting*. The proposed operator for *predicate fitting* is defined as follows.

$pfit_{(et)(ett)} \stackrel{def}{=} \lambda P_{et}.\lambda A_{et}.\emptyset \neq A \subseteq P$

This is the distributivity operator of Link (1983), which also resolves type mismatches in coordinations like *meet and sleep*, commonly used to argue against Bennett's typing.

The following examples illustrate the use of the number feature denotations and the *pfit* operator. In (1), the *pfit* operator fits the *et* type of the atom predicate *student* to the type of the singular/plural number feature. In (2), with the set predicate *meet*, type fitting is unnecessary.

(1) a. $[\![\text{student}]\!] = [\![\text{student+SG}]\!] = \mathbf{student}'_{et}\ sg_{(ett)(et)}$ (mismatch)
$sg(pfit(\mathbf{student}')) = \mathbf{student}'$ (resolution)

b. $[\![\text{students}]\!] = [\![\text{student+PL}]\!] = \mathbf{student}'_{et}\ id_{(ett)(ett)}$ (mismatch)
$id(pfit(\mathbf{student}')) = \lambda A_{et}.\emptyset \neq A \subseteq \mathbf{student}'$ (resolution)

(2) a. $[\![\text{meets}]\!] = [\![\text{meet+SG}]\!] = sg_{(ett)(et)}(\mathbf{meet}'_{ett}) = \lambda x_e.\mathbf{meet}'(\{x\})$

b. $[\![\text{meet}]\!] = [\![\text{meet+PL}]\!] = id_{(ett)(ett)}(\mathbf{meet}'_{ett}) = \mathbf{meet}'$

Note that the composition of the singularity feature denotation *sg* with the *pfit* operator gives the identity function on the *et* domain, as stated below.

Fact 1 *For every* P_{et}*:* $sg(pfit(P)) = P$.

This means that in the proposed mechanism singular morphology has no semantic effect on the lexical denotation of atom predicates, just like plural morphology (whose meaning is *id*) does not trigger any change in the denotation of set predicates.

Unlike predicates, all lexical *determiners* are assumed to range over atoms: their type is uniformly the standard $(et)(ett)$. In a singular sentence like *no student sleeps* we get the following standard analysis.

(3) $\mathbf{no}'_{(et)(ett)}(\mathbf{student}'_{et})(\mathbf{sleep}'_{et})$
$\Leftrightarrow \mathbf{student}' \cap \mathbf{sleep}' = \emptyset$

In the singular sentence *no committee meets*, the denotation of the singular set predicate *meets* is derived using the *pfit* and *sg* operators, which leads to the following (plausible) interpretation.

(4) $\mathbf{no}'_{(et)(ett)}(\mathbf{committee}'_{et})(sg(pfit((\mathbf{meet}'_{ett}))))$
$\Leftrightarrow \mathbf{committee}'_{et} \cap \{x_e : \mathbf{meet}'_{ett}(\{x\})\} = \emptyset$.

In plural sentences like *no students slept* or *all the committees met*, we get a type mismatch between the $(et)(ett)$ determiner and the *ett* plural noun. This is resolved by combining two different processes of *counting* and *existential quantification*. To illustrate the semantic outcome of these processes in full generality, consider the following example.

(5) Exactly five students met.

The exact *counting* of students who met in (5) is achieved in two steps: (i) a *conservativity step*, intersecting the denotation of *meet* with the denotation of *students*; (ii) a *participation step*, unioning both sets of sets that serve as arguments of the determiner. This leads to the following analysis.

(6) $\mathbf{exactly\_5}'(\cup pfit(\mathbf{student}'))(\cup(\mathbf{meet}' \cap pfit(\mathbf{student}')))$
$\Leftrightarrow |\{x \in \mathbf{student}' : \exists A \subseteq \mathbf{student}'[x \in A \wedge \mathbf{meet}'(A)]\}| = 5$

In words: the total number of students who participated in student meetings is exactly five.

The counting process is defined in general below as a relation between a determiner and two *ett* predicates.[4]

Definition 1 *We say that a determiner* $D_{(et)(ett)}$ counts *the ett predicates* $\mathcal{A}$ *and* $\mathcal{B}$*, and denote* $\mathbf{count}(D)(\mathcal{A})(\mathcal{B})$*, iff* $D(\cup\mathcal{A})(\cup(\mathcal{A} \cap \mathcal{B}))$ *holds.*

Counting does not yet make sure a meeting of five students actually took place in sentence (5), as intuitively required. For instance, if the only sets of students in the extension of the predicate *meet* are the sets $\{s_1, s_2\}$ and $\{s_3, s_4, s_5\}$, where $s_1, ..., s_5$ are different students, then (6) is formally true whereas sentence (5) is intuitively false, or highly incoherent. To capture this effect, we add an additional existential process to the **count** condition. This process is a slightly modified version of the proposal in Szabolcsi (1997) to quantify over *witness sets*. A set W is a *witness* of a determiner D and a set A iff $W \subseteq A$ and $D(A)(W)$ holds. The *witness condition* between a determiner $D_{(et)(ett)}$ and two *ett* predicates is defined as follows.

Definition 2 *We say that a determiner* D witnesses *the ett predicates* $\mathcal{A}$ *and* $\mathcal{B}$*, and denote* $\mathbf{wit}(D)(\mathcal{A})(\mathcal{B})$*, iff either* $\mathcal{A} \cap \mathcal{B} = \emptyset$ *or there exists* $W \in \mathcal{A} \cap \mathcal{B}$ *such that* $D(\cup\mathcal{A})(W)$ *holds.*

In other words: D witnesses $\mathcal{A}_{ett}$ and $\mathcal{B}_{ett}$ iff whenever $\mathcal{A} \cap \mathcal{B}$ is not empty it includes a witness of D and $\cup\mathcal{A}$. For (5), the witness condition derives the following requirement.

(7) $\mathbf{wit}(\mathbf{exactly\_5}'_{(et)(ett)})(pfit(\mathbf{student}'_{et}))(\mathbf{meet}'_{ett})$
$\Leftrightarrow [\exists A \subseteq \mathbf{student}'[A \neq \emptyset \wedge \mathbf{meet}'(A)]] \rightarrow \exists A \subseteq \mathbf{student}'[|A| = 5 \wedge \mathbf{meet}'(A)]$

In words: if any student(s) met then there was a meeting of exactly five students.

In Scha (1981) and Van der Does (1993) the existential effect is obtained by a separate reading of determiners, in addition to a "neutral" reading that generates analyses as in (6) (cf. footnote 4). This ambiguity strategy suffers from the fact that neither reading is completely adequate to the semantics of sentences like (5). As mentioned above, the counting reading in (6) ignores the implication in (5) that a meeting of exactly five students took place. The existential reading (7) requires the existence of such a meeting, but creates a more severe problem pointed out in Van Benthem (1986:52-53): "existential" readings like (7) actually allow more than five students to participate in meetings in a sentence like (5). In this way, the existential reading counter-intuitively models all quantifiers as upward monotone.

To solve these problems, the **wit** operator is devised so that it combines well with the counting reading into a *unified* operator for quantification with plurals. The conjunction of (6) and (7) correctly analyzes plural sentences like (5) without hurting the (non)monotonicity properties of determiners.

[4]This counting process has semantic implications similar to the "neutral" reading of Scha (1981), which is defined in Van der Does (1993) as a relation N between a determiner, an *et* predicate and another *ett* predicate: $\mathrm{N}(D_{(et)(ett)})(A_{et})(\mathcal{B}_{ett}) = \mathbf{count}(D)(pfit(A))(\mathcal{B})$.

sentences of $L_{F/E}$ we may define a set of preferred worlds G indistinguishable regarding their goal status $G = \{w \mid \neg wRw \wedge \exists v : wRv\}$. A state of satisfaction $\sigma' = \langle P, \emptyset \rangle$ is reached after (1) an agent receives an information $Est(\varphi)$ in state σ such that: $\sigma \in \mathbf{M} \wedge \forall w(\sigma, w \vDash \varphi \rightarrow w \in G_\sigma) \wedge [Est(\varphi)]\,\sigma = \sigma'$, or (2) an agent in state σ receives an order $Fiat\,(\varphi)$such that: $\sigma \in \mathbf{I} \wedge [Fiat\,(\varphi)]\,\sigma = \sigma'$.

Fiat/Est logic is decidable. A simple decision procedure may be given under some simplifying assumptions (by reducing the set of compound sentences to $\neg\varphi$, $\varphi \wedge \psi$, $\Diamond\varphi$ and by weakening metaphysical modality to $\boxplus$: $[Est\,(\boxplus\,(\varphi))]\,\sigma = \sigma'$ iff $\forall\sigma''\,(\sigma'' =_R \sigma' \rightarrow [M\,(\neg\varphi)]\,\sigma'' \in \mathbf{F})$, etc.).The decision procedure consists in creating two interconnected 'world elimination tables' in which worlds are eliminated according to the semantics of sentences, and in testing whether the conclusion is accepted.

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Addresses and Affiliations

Pieter Adriaans p.adriaans@syllogic.com
University of Amsterdam and Syllogic, ILLC/WINS
Plantage Muidergraacht 24
1018 TV Amsterdam
Nederland

Maria Aloni aloni@hum.uva.nl
University of Amsterdam, ILLC/Department of Philosophy
Nieuwe Doelenstraat 15
1012 CP Amsterdam
Nederland

Horacio Arlo-Costa hcosta@andrew.cmu.edu
Carnegie Mellon University, Philosophy Department
135 Baker Hall
Pittsburgh, PA 15213
U.S.A.

David Beaver dib@stanford.edu
Stanford University, Department of Linguistics
Stanford CA 94305-2150
U.S.A.

Sigrid Beck sbeck@sp.uconn.edu
University of Connecticut, Department of Linguistics
341 Mansfield Road, U-145
Storrs, CT 06269
U.S.A.

Agnes Bende-Farkas agnes@ims.uni-stuttgart.de
Universität Stuttgart, IMS
Azenbergstraße 12
D-70174 Stuttgart
Deutschland

Martin van den Berg vdberg@pal.xerox.com
FX Palo Alto Laboratory,
400 Hillview Ave Building 4
Palo Alto CA 94304
U.S.A.

Remko Bonnema remko.bonnema@hum.uva.nl
University of Amsterdam, Institute for Logic, Language and Computation
Spuistraat 134
1012 VB Amsterdam
Nederland

Paul Buying buying@wins.uva.nl
University of Amsterdam, Artifical Intelligence
Plantage Muidergracht 24
1018 TV Amsterdam
Nederland

Brady Zack Clark bzack@leland.stanford.edu
Stanford University, Department of Linguistics
Stanford CA 94305-2150
U.S.A.

Robin Clark rclark@babel.ling.upenn.edu
University of Pennsylvania, Department of Linguistics
Philadelphia, PA 19104
U.S.A.

Alexis Dimitriadis alexis@ling.upenn.edu
University of Pennsylvania, Department of Linguistics
Philadelphia, PA 19104-6305

Edit Doron edit@vms.huji.ac.il
Hebrew University of Jerusalem, Department of English Languages
91905 Jerusalem
Israel

Markus Egg egg@coli.uni-sb.de
Universität des Saarlandes, Computerlinguistik, Geb. 17.2
D-66041 Saarbrücken
Deutschland

Tim Fernando Tim.Fernando@tcd.ie
Trinity College Dublin, Computer Science
Dublin 2
Ireland

Anthony S. Gillies agillies@u.arizona.edu
University of Arizona, Department of Philosophy
Tucson, AZ 85721
U.S.A.

Jonathan Ginzburg msjihad@mscc.huji.ac.il,ginzburg@ling.gu.se
King's College (and Hebrew University of Jerusalem), Department of Philosophy
The Strand
London WC2R 2LS
U.K.

Danièle Godard godard@univ-lille3.fr
CNRS and Lille III,
3 Square du Croisic
75015 Paris
France

Javier Gutiérrez-Rexach gutierrez-rexach.1@osu.edu
Ohio State university, Cunz Hall
Columbus OH 43210-3269
U.S.A.

Erik de Haas e.de.haas@syllogic.com
University of Amsterdam and Syllogic, ILLC/WINS
Plantage Muidergraacht 24
1018 TV Amsterdam
Nederland

Caroline Heycock heycock@ling.ed.ac.uk
University of Edinburgh, Department of Theoretical and Applied Linguistics
Edinburgh EH8 9LL

Gerhard Jäger jaeger@zas.gwz-berlin.de
Zentrum fuer Allgemeine Sprachwissenschaft,
Jägerstraße 10/11
D-10117 Berlin
Deutschland

Theo M.V. Janssen theo@wins.uva.nl
University of Amsterdam, Computer Science
Plantage Muidergracht 24
1018 TV Amsterdam
Nederland

Jan Jaspars jaspars@wins.uva.nl
University of Amsterdam, Department of Mathematics and Computer Science
Plantage Muidergracht 24
1018 TV Amsterdam
Nederland

Jacques Jayez jjayez@dial.oleane.com
EHESS,
54 Boulevard Raspail
75006 Paris
France

Aravind Joshi joshi@linc.cis.upenn.edu
University of Pennsylvania, Institute for Research in Cognitive Science
3401 Walnut Street
Philadelphia PA 19104-6228
U.S.A.

Reinhard Kahle reinhard.kahle@uni-tuebingen.de
Universität Tübingen, WSI
Sand 13
D-72076 Tübingen
Deutschland

Laura Kallmeyer lk@sfs.nphil.uni-tuebingen.de
Universität Tübingen and University of Pennsylvania, Sonderforschungsbereich 441 and IRCS
Köstlinstraße 6
D-72074 Tübingen
Deutschland

Ruth Kempson rk@soas.ac.uk
King's College London, Philosophy Department
The Strand, London WC2R
U.K.

Brenda Kennelly brenda.kennelly@let.uu.nl
University of Utrecht, OTS
Trans 10
3512 JK Utrecht
Nederland

Rodger Kibble rodger.kibble@itri.brighton.ac.uk
University of Brighton, ITRI
Lewes Road
Brighton BN2 4GJ
U.K.

Alexander Koller koller@coli.uni-sb.de
Universität des Saarlandes, Department of Computational Linguistics
66041 Saarbrücken
Deutschland

Peter Krause peter@ims.uni-stuttgart.de
University of Stuttgart, Institute for Computational Linguistics
Azenbergstraße 12
70174 Stuttgart
Germany

Seth Kulick skulick@linc.cis.upenn.edu
University of Pennsylvania, Institute for Research in Cognitive Science
3401 Walnut Street, Suite 400A
Philadelphia, PA 19104-6228
U.S.A.

Natasha Kurtonina natashak@linc.cis.upenn.edu
University of Pennsylvania, Institute for Research in Cognitive Science
3401 Walnut Street, Suite 400A
Philadelphia, PA 19104-6228
U.S.A.

Alice ter Meulen atm@let.rug.nl
University of Groningen, Department of English
PO Box 716
9700 AS Groningen
Nederland

Wilfried Meyer-Viol meyervio@dcs.kcl.ac.uk
King's College London, Philosophy Department
The Strand, London WC2R
U.K.

Christof Monz christof@wins.uva.nl
University of Amsterdam, Institute for Logic, Language and Computation
Plantage Muidergracht 24
1018 TV Amsterdam
Nederland

Rick W.F. Nouwen rick.nouwen@let.uu.nl
University of Utrecht, UiL-OTS
Trans 10
3512 JK Utrecht
Nederland

Rainer Osswald rainer.osswald@fernuni-hagen.de
Fernuniversität Hagen, Informatikzentrum
Feithstraße 142
58084 Hagen
Deutschland

Rohit Parikh ripbc@cunyvm.cuny.edu
City University of New York, Computer Science, Mathematics and Philosophy
63 East 9th Street, #7M
New York, NY 10003

Marc Pauly pauly@cwi.nl
Centrum voor Wiskunde en Informatica,
PO BoX 94079
1090 GB Amsterdam
Nederland

Richard Power Richard.Power@itri.brighton.ac.uk
University of Brighton, ITRI
Lewes Road
Brighton BN2 4GJ
U.K.

Fabien Reniers fabien.reniers@let.uu.nl
University of Utrecht, OTS
Trans 10
3512 JK Utrecht
Nederland

Robert van Rooy vanrooy@hum.uva.nl
University of Amsterdam, Department of Philosophy
Nieuwe Doelenstraat 15
1012 CP Amsterdam
Nederland

Ivan Sag sag@csli.stanford.edu
Stanford University, Department of Linguistics
Stanford, CA 94305
U.S.A.

Remko Scha remko.scha@hum.uva.nl
University of Amsterdam, Institute for Logic, Language and Computation
Spuistraat 134
1012 VB Amsterdam
Nederland

Isabelle Tellier tellier@univ-lille3.fr
Université Charles de Gaulle-Lille3, Laboratoire d'Informatique Fondamentale de Lille
59653 Villeneuve d'Ascq Cedex
France

C.F.M. Vermeulen kees.vermeulen@phil.uu.nl
Utrecht University, Departments of Philosophy and Linguistics
Trans 10
3512 JK Utrecht
Nederland

Louise Vigeant lvigeant@leland.stanford.edu
Stanford University, Department of Linguistics
Margaret Jacks Hall – Building 460
Stanford CA 94305
U.S.A.

Yoad Winter winter@cs.technion.ac.il
Technion, Computer Science
Haifa 32000
Israel

Roberto Zamparelli roberto@cogsci.ed.ac.uk
University of Edinburgh, Human Communication Research Centre
Edinburgh EH8 9LW

Berislav Žarnić berislav@pmfst.hr
University of Split, Teacher's College
Vukovarska 59
21000 Split
Croatia

Henk Zeevat henk@hum.uva.nl
University of Amsterdam, ILLC/Computational Linguistics
Spuistraat 134
1012 VB Amsterdam
Nederland