The Semantics of Count Nouns

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Abstract. We offer an account of the semantics of count nouns based on the observation that for some count nouns, the set of atoms in the denotation of the singular predicate is contextually determined. We derive the denotation of singular count nouns relative to a context k, where k is a set of entities which count as atoms in a particular context. An operation $COUNT_k$ applies to the mass noun denotation N_{mass} and derives the count meaning: a set of ordered pairs <d,k> where d is a member of N ∩ k and k is the context k relative to which d counts as one. Count nouns and mass nouns are thus typally distinct and the grammatical differences between them follow from this. We distinguish between naturally atomic predicates, which denote sets of inherently individuable entities or boolean algebras generated from such sets, and semantically aomic predicates, which denote sets which are atomic relative to a particular context k. This distinction is shown to be orthogonal to the mass count distinction.

Keywords: mass/count distinction, atomicity, counting, measuring, homogeneity, nominal interpretations,∧ semantics of number.

1 Introduction

This paper proposes a semantics for count nouns which makes explicit the grammatical basis of counting. We assume the semantics for mass nouns proposed in Chierchia,[1], according to which mass nouns denote atomic Boolean algebras generated under the complete join operation from a possibly vague set of atoms. However, we differ from Chierchia in our analysis of count nouns. Chierchia argues that the atomic elements in mass denotations cannot be grammatically accessed because a mass noun is lexically plural, i.e. the root lexical item denotes a boolean algebra. Singular count nouns denote a unique set of salient atoms, which as a consequence are grammatically accessible. Plural count nouns denote the closure of the singular denotation under the complete join operation, thus plural count nouns and mass nouns denote the same kinds of entities. The grammatical difference is only whether the set of atoms from which the boolean algebra is generated is or is not lexically accessible, where lexical accessiblity is to determined by the pragmatic accessibility of a salient, stable set of atoms (Chierchia, [2]). We argue in this paper that Chierchia's account is inadequate and that the salience or non-vagueness of a presupposed atomic set cannot be at the basis of count noun semantics. There are two reasons for this: (i) the existence of mass predicates such as *furniture* which denote sets generated from a set of non-vague, salient atoms and (ii) the existence of context dependent count nouns such as *wall* and *hedge.*

1.1 Mass nouns may denote sets of salient atoms

As Chierchia[1],[2] and Gillon [3] have pointed out, mass nouns may, like *furniture*, denote boolean algebras generated from sets of inherently individuable atoms. Barner and Snedeker [4] show that these mass nouns, in contrast to mass nouns like *mud* but like count nouns, allow quantity judgements in terms of number rather than overall volume. Thus *who has more furniture?* will be answered by comparing numbers of pieces of furniture, while *who has more sand/mud?* will be answered by comparing overall quantities of mud or sand no matter how many individual piles or heaps or units the stuff is arranged in. Rothstein[5] and Schwarzschild[6] independently show that these predicates (which Rothstein calls 'naturally atomic' and Schwarzschild calls 'stubbornly distributive) make the atomic entities salient for distributive adejctives such as *big*. Pires d'Oliviera and Rothstein [7] show that naturally atomic predicates may be antecedents for reciprocals in Brazilian Portguese, although this is impossible in English.

1.2 Singular Count Noun Denotations may be Contextually Determined

There are a significant number of count nouns which are not associated with a unique set of salient atoms: instead the set of atoms in the denotation of these count nouns may be variable and highly context dependent. Krifka [8] shows that nouns such as *sequence* and *twig* are non-quantized, and Mittwoch [9] shows that this is true also of mathmatical terms such as *plane* and *line*. Rothstein [10] shows that this generalises to clases of singular count nouns denoting sets of entities with context-dependent physical dimensions. These include nouns such as *fence*, *wall*, *hedge* and *lawn*, where the boundaries of the atomic entities are defined by cartesian coordinates, and classificatory nominals such as *bouquet/bunch*. For example, if a square of land is fenced or walled in on four sides, with the fence or wall on each side built by a different person, we can talk of one (atomic) fence/wall enclosing the field, or we can talk of the field being enclosed by four fences or wall, each one built by a different person, with the atomic units depending on the contextually relevant choice of what counts as one wall. Similarly, flowers are often sold in bunches, but I may decide that a 'predesignated' bunch of flowers is not big enough for my purposes and buy two bunches which I then put together and deliver as a single bunch. Many other such examples can be constructed. Thus, count nouns meanings must involve sets of context dependent atoms. Crucially, fences, walls and bunches in these contexts can be counted, as in four fences/two walls/two bunches of flowers, whereas furniture cannot be counted (*three furnitures), even though furniture may be naturally associated with a uniquely determined set of salient atomic entities. This indicates that the counting operation can be applied to count nouns because the association with the set of contextually relevant atoms is grammatically encoded.

2 Count Noun Denotations

We encode contextual dependence of count nouns in the following way.
We assume that nominals are interpreted with respect to a complete atomic Boolan algebra M. $\sqcup_M$, the sum operation on M is the complete Boolean join operation (i.e. for every $X \subseteq M$: $\sqcup_M X \in M$). With Chierchia, we assume that the set of atoms A of M is not fully specified, vague. The denotation of a root noun N_{root} is the Boolean algebra generated under $\sqcup_M$ from a set of atoms $A_N \subseteq A$ (so root noun denotation N_{root} has the same 0 as M, its atoms are A_N, and its 1 is $\sqcup_M(A_N)$). Mass nouns have the denotations of root nouns, so $NOUN_{mass} = NOUN_{root}$. (Note that the choice of this particular theory of mass nouns is not essential to what follows. We assume it for simplicity.) For mass nouns like *furniture,* the atoms in the denotation of the nominal will be be the salient individuable entities, while for mass nouns like *mud* the atoms will be an underdetermined vague set of minimal mud parts.
Singular count nouns denote sets of countable atoms. Counting is the operation of putting entities which are predesignated as atoms, i.e. entities that count as 1, in one-to-one correspondence with the natural numbers. We have seen that what counts as one entity is contextually determined, and hypothesise that this decision is grammatically encoded. This grammatical encoding is what makes a noun count.
We propose that singular count nouns are interpreted relative to a context k. A *context* k is a set of objects from M, $k \subseteq M$, K is the set of all contexts. The set of count atoms determined by context k is the set $A_k = \{<d,k>: d \in k\}$. A_k is going to be the set of atoms of the count structure B_k to be determined below. The objects in k are not mutually disjoint with respect to the order in M, since we may want, in a single context my hands and each of my fingers to count as atoms, i.e. to be members of the same contextual set of atoms. Thus it may be the case that for two entities lt and lh (my left thumb and my left hand), $lt \sqsubseteq_M lh$, but nevertheless $lt, lh \in k$. In that case $<lt,k>, <lh,k> \in A_k$. So both my left thumb and my left hand are atoms to be counted in context k. Given this we cannot lift the order on the count Boolean domain from the mass domain.
We want the count domain B_k to be a complete atomic Boolean algebra generated by the set of atoms A_k. Up to isomorphism, there is only one such such structure, B_k.

Definition of B_k: B_k is the unique complete atomic Boolean algebra (up to idomorphism) with set of atoms A_k. We let $\sqcup_k$ stand for the corresponding complete join operation on B_k.

However, we would like to lift this order from the mass domain as much as we can. If $k' \subseteq k$ and k' is a set of mutually non-overlapping objects in M, there is no problem in lifting part-of relations of the sums of k'-objects from the mass domain. (k' is a set of mutually non-overlapping objects in M iff for all $d, d' \in k'$: $d \sqcap_M d' = 0$). Thus we impose the following constraint on B_k:

Constraint on B_k: For any set $k' \subseteq k$ such that the elements of k' are mutually M-disjoint, the Boolean substructure $B_{k'}$ of B_k is given by: $B_{k'} = \{<\sqcup_M X,k>: X \subseteq k'\}$ with the order lifted from $\sqcup_M$.

The plurality order is not lifted from the mass domain for objects that overlap. i.e. the sum of my hands and my fingers is a sum of twelve atoms, hence not lifted from the mass domain (*atom*, here is a metalanguage predicate).
(Singular) **count predicates**, in particular count nouns, denote subsets of A_k, and are derived as follows. All lexical nouns N are associated with a root noun meaning $N_{root.}$ (see above). This root noun meaning is a Boolean algebra generated under $\sqcup_M$ from a set of M-atoms. As noted above, $N_{mass} = N_{root} \subseteq M$.

Count nouns are derived from root noun meaning by an operation $COUNT_k$ which applies to the root noun N_{root} and picks out the set of ordered pairs $\{<d, k>: d \, \varepsilon \; N \cap k\}$. These are the entities which in the given context k count as atoms, and thus can be counted. The parameter k is a parameter manipulated in context. Thus, in the course of discourse we have as many relevant ks around as is contextually plausible. We can think of these contexts as contextually defined perspectives on a situation or model, and the set of contextually relevant contexts is rich enough so that there may be different numbers of N entities in a situation depending on the choice of k, i.e the choice of counting perspective that is chosen. In sum:

$$\text{For any } X \subseteq M\text{: } COUNT_k(X) = \{<d, k>: d \, \varepsilon \; X \cap k\} \qquad \textbf{(1)}$$

The interpretation of a count noun N_{count} in context k is: $N_{count} = COUNT_k(N_{root})$.
We will use N_k for this interpretation of N_{count} in k.

The denotation of a singular count noun is thus an ordered pair whose first projection is a set of entities $N_{root} \cap k$, and whose second projection is context k.
We call such sets *semantically atomic sets,* since the criterion for what counts as an atom is semantically encoded by the specification of the context. The set $N_{root} \cap k$ is the set of semantic atoms in N_{root} relative to k. This is the set of atomic N-entities used to evaluate the truth of an assertion involving N_{count} in a particular context k, i.e. N_k.

The atoms in k are not constrained by a non-overlap condition, since we want to allow examples such as those *I can move my hand and my five fingers* and *It took 2500 bricks to build this wall* which make reference to atomic elements and their atomic parts. Non-overlap is not irrelevant though, I assume it comes in as a constraint on default contextual interpretations:

Constraint on count predicates: In a default context k, the interpretation of singular count predicate P is a set of mutually non-overlapping atoms in k (where <a,k> and <a',k> don't overlap iff $a \sqcap_M a' = 0$)

This guarantees that when we count entities in the denotation of N_k we will be counting contextually discrete, non-overlapping entities.

Plural count nouns are are derived from singular count noun meanings, using the standard plural operation, defined in the current count structures, and thus adapted to thefor the meaning of the count noun. The plural operation gives the closure of $N_{root,k}$

under the sum operation, while keeping track of the context. Link's plural operation (Link 1983) is as follows:

$$*A = \{d: \exists Y \subseteq A_k: d=\sqcup Y\} \quad (2)$$

For a relation N_k we define the n-th projection of N_k as follows:

$$\pi_1(N_k) = \{d: <d,k> \in N_k\} \quad (3)$$

$$\pi_2(N_k) = k \quad (4)$$

For convenience we also define π_n directly for pairs:

$$\pi_1(<d,k>) = d \quad (5)$$

$$\pi_2(<d,k>) = k$$

Note that for any $<d,k> \in N_k$, $\pi_2(<d,k>) = \pi_2(N_k) = k$.
With this we lift the *-operation to the present count structures:

$$\text{In default context k: } PL(N_{count}) = *N_k = \{<d,k>: d \in *\pi_1(N_k)\} \quad (6)$$

(In non-default contexts, we don't lift plurality from the mass domain. Thus in non-default context k: $*\pi_1(N_k) = \{d: \exists Y \subseteq A_k: d=\sqcup_k Y\}$)

We stress several important points: first, the non-overlap condition in the constraint on count predicates guarantees that in default contexts, the order of the plural count noun denotation is lifted directly from M. So the denotation of the plural count noun depends on the contextually determined denotation of the singular N_k. The plural noun denotes a set of ordered pairs where the first element is in the closure of $N_{root,k}$ under sum and the second element is the context k.. $N_{root,k}$ may vary depending on choice of k, and the denotation of the plural set will similarly vary, depending on $N_{root,k}$. Crucially, the information about the context determining the set of atoms is preserved in the plural denotation. There is no guarantee that, even with a predicate like *hair*, $HAIR_{root,k}$ and the set of atoms in the $HAIR_{root}$ is the same set. So though *the hair* and *the hairs* may well refer to the same real-world entity, there is no guarantee that they do so. Second, since k itself is not constrained by a non-overlap condition, the plural domain may contain elements not lifted from M. These will not be in the denotations of lexical predicates, but they will be in the denotations of other expressions built up in the grammar like the conjunctive definite *my hand and its five fingers.* The grammatical operation of counting will consist of the modification of N expressions by numerical modifiers and it will apply at the N level. In a normal context, *my hand* counts as an atom, and *its five fingers* counts as a sum of five finger; consequently in k *my hand and its five fingers* will denote a sum of 6 atoms. However, we will not normally count across conjunctions, thus, *I moved my hand and its five fingers*, does not imply a felicitous use of *Hence I moved six body parts,* since the predicate *body part* in a default context will be interpreted as denoting a set of non-overlapping objects. For a discussion of non-default contexts, and situations where overlapping entities are felicitously counted, see Rothstein 2009.

To conclude this section, we survey the range of possible nominal denotations:

Root nouns: $N_{root} \subseteq M$: Root nouns denote a Boolean algebra of mass entities, the closure of a set of atoms in M under the sum operation $\sqcup_M$.
Mass nouns: $N_{mass} = N_{root}$: Mass nouns just are root nouns.
Singular count nouns: $N_k \subseteq M \times \{k\}$: A singular count noun denotes a set of ordered pairs of which the first projection is $N_{root,} \cap k$, a subset of N_{root} whose members do not (generally) overlap, and the second projection is the context k. The denotation of a count noun such as *fence* is context dependent, since the choice of atoms depends on the $COUNT_k$ operation, which itself is dependenton the choice of context k.
Plural nount nouns: In a default context k, $PL(N_k) \subseteq M \times \{k\}$, where the first projection is the closure of $N_{root} \cap k$ under sum, and the second projection is k.

3 Implementing the Analysis

Mass nouns and count nouns are of different types: mass nouns denote subsets of D, and thus of type <d,t>; count nouns denote subsets of $D \times K$ and are of type <<d×k>, t>. In this section we explore how this works compositionally:

3.1 Operations which are not Sensitive to the Count/Mass distinction

Adjectival modification: Some grammatical operations apply equally well to both types, for example adjectival modification as in *an expensive chair*, *expensive furniture*. We treat *expensive* as denoting a property of individuals, which in its attributive reading shifts to the predicate modifier type <<d,t>,<d,t>>. As a predicate modofier, *expensive* applies to mass nominal expressions of type <d,t>, denoting the function $\lambda P \lambda x.P(x) \wedge EXPENSIVE(x)$. (P is a variable over expressions of type <d,t>.) We assume a count modifier $EXPENSIVE_{Count'}$ modifying expresions of type <d×k, t>, and which is defined in terms of EXPENSIVE, using the π_n function defined in (5). ($\mathcal{P}$ is a predicate variable type <d×k, t>, and *x* is a variable of type $d \times k$). $EXPENSIVE_{Count}$ denotes the function $\lambda \mathcal{P} \lambda x. \mathcal{P}(x) \wedge EXPENSIVE(\pi_1(x))$.

Conjunction: Conjunction of count and mass nouns such as *tables and other furniture* must be at the type of mass noun. This is shown in the partitive constructions in (6), where a conjunction of mass and count noun can occur in the partitive only with mass determiners:

*Three/Many of [the tables and the furniture] arrived damaged. (7)
Some/Much of the tables and the furniture arrived damaged. (8)

We assume that *and* conjoins arguments at the same type. In cases of type mismatch, the count nouns lowers to a mass reading via the π_n function.

$$||\text{tables and (other) furniture}|| = \text{AND}(\pi_1(||\text{ tables }||), ||\text{ furniture }||) = \text{AND}(^*\text{TABLES}_{root,k}, \text{FURNITURE}) \quad (9)$$

3.2 Operations Which Distinguish Between Mass and Count Nouns

Grammatical counting: Grammatical counting, i.e. modification by numerical expressions is sensitive to the count/mass distinction. We propose that number expressions are sensitive to the typal difference between mass and count nouns. Numerical expressions such as *three* denote functions from <d×k, t> into <d×k, t>, and thus cannot apply to mass nouns. *Three* applies to a set of ordered pairs N_k and gives the subset of N_k, such that all members of $\pi_1(N_k)$ are plural entities with three parts each of which is an entity in k.

$$||\text{Three}|| \, (N_{count}) = \lambda\mathcal{P}\lambda x.\, \mathcal{P}(x) \wedge |\pi_1(x)|_{\pi2(\mathcal{P})} = 3 \quad (10)$$

Three denotes a function which applies to a count predicate N_k and gives the subset of ordered pairs in N_k, where the first projection of each ordered pair has three parts which count as atoms in k.

Determiner selection: Determiners are sensitive to the typal difference between <d,t> and <d×k, t>, as in *every chair* vs **every furniture*.

Partitive constructions: Partitive constructions such as *three of the chairs of the furniture* are sensitive to the properties of the nominal head of their complement, The determiner heading a partitive shows the same selectional restrictions with respect to the nominal head of its complement as determiners usually show within a bare DP: *three of the chairs/three chairs; *three of the furniture/*three furniture(s);*much of the chairs/*much chairs; much of the furniture/much furnitures;* We thus need to recover the predicate expression from the DP. This is possible because operations involved in the construction of the DP keep track of the original context k at all stages. The partitive operates on a definite complement, which is defined using Link's [11] operation:

For mass nouns: *the* N = $\sqcup$N, the (unique) maximal entity in N (11)
For count nouns: *the* N_k = $\langle \sqcup\pi_1(N_k), k\rangle$

We lift the part-of relation on ordered pairs in M × {k} from M: $\langle x_1, k\rangle \sqsubseteq_k \langle x_2, k\rangle$ iff $x_1 \sqsubseteq_M x_2$.

The partitive operation follows the following definition schema: it operates on a definite complement and gives the set of parts: PARTITIVE ($\sqcup$N) = {x: x $\sqsubseteq$ ($\sqcup$N)}

For a mass predicate, PARTITIVE($\sqcup_M(N_{mass})$) = {x: x $\sqsubseteq_M$ $\sqcup_M(N_{mass})$}, i.e. N_{mass} .

For a count predicatein context k, PARTITIVE($\sqcup_k(N_k)$) is again lifted from M:
PARTITIVE ($\sqcup_k N_k$) = $\{<x,k>: <x,k> \sqsubseteq_k <\sqcup_M(\pi_1(N_k)), k>\}$

Crucially, since we kept track of the context k during all the operations involving the composition of the embedded DP, the operation giving the set of parts of $\sqcup N_k$ will still have access to the original context k. Partitive determiners apply to the result of applying PARTITIVE to the DP meaning, exactly as they would apply to NP within the DP. Since *three* makes use of the parameterized cardinality function which makes reference to k., it can apply to PARTITIVE(*the chairs*) or PARTITIVE(*the pieces of furniture*) which denote sets of type $<d \times k,t>$, but not to PARTITIVE(*the furniture*), which denotes a set of type $<d,t>$. *Some* applies equally well to both types.

Reciprocal resolution: Reciprocal resolution is sensitive to the mass/count distinction. A reciprocal must have cannot take a mass noun as antecedent although it is 'lexically plural'. We assume that reciprocals (in English) are constrained to take as antecedents plural entities in $D \times \{k\}$. We assume that the antecedent for a reciprocal must be a plural entity in We use this constraint to explain Gillon's observation in [3] that *The curtains and the carpets resemble each other* (the 'count' reciprocal) is ambiguous between the collective reading in which the sum of curtains resembles the sum of carpets and vice versa and the distributive reading in which each member of the set CURTAINS ∪ CARPETS resembles all the other members of the set. The mass counterpart, *the curtaining and the carpeting resemble each other*, has only the first collective reading. Space constraints prevent giving a full analysis here, but the outline of the explanation is as follows.
On the distributive reading of the count reciprocal, the conjoined DP *the curtains and the carpets* denotes the sum of the maximal plurality of curtains and the maximal plurality of carpets. and the interpretation of the reciprocal requires every two atomic entities (i.e. atomic individuals in the denotation of $CURTAINS_k \cup CARPETS_k$) to resemble each other. On the second reading of this sentence, the curtains as a group, or singular collectivity, resemble the curtains as a group, or singular collectivity, and vice versa. On this reading ⊔CURTAINS and the sum of carpets, ⊔CARPETS are treated as collections (see [12]) and are raised to the group-atoms GR($\sqcup CURTAINS_k$) and GR($\sqcup CARPETS_k$). We assume that raising to group atoms is relative to a context k, and that the group atoms are indexed for the context in which they are atomic. Group atoms thus have their denotations in $D \times \{k\}$, and pluralities of group atoms such as *the curtains and the carpets* can be antecedents for reciprocals.
When the antecedent of the reciprocal is *the curtaining and the carpeting*, the distributive reading is not available. This is because *curtaining* and *carpeting* are nominals of type $<d,t>$ and the definites denote maximal sums of entities in the mass domain M. However, the group reading is available since ⊔CURTAINING and ⊔CARPETING can be raised to atomic collectivities GR(⊔CURTAINING) and GR(⊔CARPETING) respectively, and the conjunction denotes a plurality of atoms in the count domain.

4 Formal Atomicity, Natural Atomicity and Semantic Atomicity

This account we have assumes a single domain M, and analyses the count/mass distinction as a typal distinction between mass predicates which are simple predicates denoting subsets of the domain M and (singular) count predicates denoting denoting sets of indexed entities, where the index indicates the context in which they count as one. Count nouns are derived from mass nouns (or root nouns) by a lexical operation $COUNT_k$, picking out those entities in N_{root} which count as atoms in the context k and indexing them as such. While similar to Krifka [13,14], insofar as both this and Krifka's account derives count nouns from mass nouns by a lexical operation, the theories are very different conceptually and formally. Krifka proposes analysing count nouns as extensive measure functions of type <n, <d,t>> which apply to a number to give a measure predicate. *Cattle* is a mass predicate of type <d,t>, denoting λx. CATTLE(x). It is similiar in meaning to the root noun COW, in fact we can assume for our purposes that they are synonymous. The count nouns COW' is derived from COW (or CATTLE) and denotes $\lambda n \lambda x.COW(x) \wedge NATURAL\ UNIT(x) = n$. This applies to a number and yields a count predicate, indistinguishable in type from the mass noun, but with a different meaning. In the absence of an explicit number word, the predicate is reduced from <n, <d,t>> to <d,t> via existential quantification over the n argument. Crucially, for Krifka, the typal difference between mass and count terms is neutralised before the higher nodes of the N tree are constructed. In the theory presented here, the typal difference persists up to the DP level and allows grammatical operations such as partitive construction and reciprocal resolution to exploit the typal constrast. This technical difference reflects a deeper conceptual difference. Krifka analyses count nouns as extensive measure functions directly analogous to expressions such as *kilo* and ***litre.*** We start here from the premise that measuring and counting are very different operations: measuring assigns a quantity a value on a dimensional scale, while counting puts entities in one-to-one correspondence with the natural numbers. I pursue this contrast between measuring and counting in ongoing research. [15].

The theory developed here allows allows us to distinguish three kinds of atomicity. (i) Formally atomic sets are sets of atoms which generate atomic Boolean algebras under the complete join operation. These sets may be vague and/or underspecified; (ii) Semantically atomic sets which are derived via the $COUNT_k$ operation and denote sets of entities which are atomicin a specified context k.; These sets are grammatically countable. (iii) Naturally atomic sets, which are sets of inherently individuable entities, and which may generate denotations for mass nouns as well as for plural count nouns e.g. *child* and *furniture* are naturally atomic count and mass predicates respectively, while *fence* and *mud* are examples of count and mass predicates which are not naturally atomic. Naturally atomic mass predicates make possible quantity judgements based on number rather than volume as in "*who has more furniture"* [4](Barner and Snedeker 2005). They are semantically relevant since they may host districutive predicates such as *big* [which distribute over natural atoms (see 3). Pires d'Oliveira and Rothstein [ ] show that in Brazilian Portuguese they may be antecedents for reciprocals. However, natural atomicity is neither a necessary nor sufficient condition for count semantics.

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