# Counting and the Mass-Count Distinction

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**Abstract**
This paper offers an account of the semantics of count nous. I show that neither the atomic/non-atomic distinction nor the homogeneous/non-homogeneous distinction is sufficient to explain the semantic contrast between mass and count nouns, since there are mass nouns which are atomic, and there are count nouns which are homogeneous. Starting from a version of Chierchia's 1998a account of the semantics of mass nouns under which the mass and count domains are atomic, I show that the denotation of singular count nouns is derived via a measure operation which picks out sets of non-overlapping entities which count as one by a recoverable unit of measurement. These entities I call 'semantic atoms'. Since the choice of unit of measurement may be context dependent, the denotation of a count noun may be context dependent too. Grammatical operations, including, but not restricted to, counting require access to sets of semantic atoms, thus count nouns but not mass nouns can be directly modified by numerals. A third relevant notion of atomicity, to be distinguished from both formal and semantic atomicity, is natural atomicity. This is a (gradable) property of predicates which denote entities which (usually) come in inherently individuable units. The derivation of count nouns may make use of natural atomic structure, but this is not necessary. As Barner and Snedeker 2005 show, mass nouns as well as count nouns may be naturally atomic.

## 1. Introduction: What is the mass/count distinction?

This paper offers an account of the semantics of count nouns. While quite a lot of research in formal semantics has investigated the relation between the mass domain and the count domain, most of it has focused on the semantics of mass nouns (an exception being Krifka 1989, which we will discuss below). In particular, discussion has centred around the question of whether mass nouns gets their denotation in a non-atomic or an atomic domain, or to put it rather differently, whether the minimal parts of mass noun denotations are visible to the language user. Proponents of the non-atomic view include Link 1983, and Landman 1989, while proponents of the atomic approach are Gillon 1992, Chierchia 1998 and Landman 2006. In this paper, however, I assume a version of an atomic theory of mass nouns based on Chierchia 1998, and focus on the semantics of the count domain. While it has generally been assumed that the count domain is atomic, I show that this assumption by itself is insufficient to explain the behaviour of count nouns, and that it must be supported by a theory of what atomicity actually is. I show that to explain the linguistic behaviour with respect to mass and count nouns we need to distinguish between formal atomicity (by which I mean being an atom in a Boolean structure), natural atomicity and what I shall call semantic atomicity.

The paper is structured as follows. In the remainder of this section I review evidence that the mass/count distinction is a grammatical distinction independent of the structure of matter. I then review arguments that the mass/count distinction cannot be defined in terms of homogeneity or an non-atomic/atomic contrast, (section 2) and present the arguments that the mass domain is an atomic domain (section 3). Section 4 reveiws psycholinguistic evidence from Barner and Snedeker 2005 that supports this approach. Section 5-9 sets up a semantics for count nouns based on the hypothesis that atomicity in the mass domain is formal atomicity, i.e. having a particular position in a Boolean lattice, while atomicity in the count domain is semantic atomicity. Semantic atomicity is having the property of measuring 1 by some recoverable criterion of unit measurement. Playing a role in our language use in both the mass and count domains is a third notion of natural atomicity, which is roughly speaking a property of predicates which come in inherently individuable units. We shall see that it overlaps with both formal and semantic atomicity, but that all three notions are distinct and must be defined independently. In the final section of the paper, I discuss some remaining issues which any theory of count and mass nouns has to deal with, and show how they are worked out in this account.

In general, the mass/count distinction has attracted a lot of attention among syntacticians, semanticists and psycholinguists, because it represents an apparent split between grammar and 'the world'. While the mass/count distinction reflects in some ways the fundamental ontological distinction between 'stuff' or 'substance' on the one hand and 'objects' or 'things' on the other, it is none the less an independent grammatical distinction which is cannot be learned on the basis of conceptual distinctions between objects and stuff. Whether or not a noun in a particular language has count syntax or mass syntax is not fully predictable on the basis of the real world properties of its denotation, although there maybe tendencies and patterns which differ in their details from language to language. We begin by reviewing the evidence that the mass/count distinction is an distinction independent of the properties of matter, from which it follows that the mass/count status of a nominal cannot be deduced on the basis of the properties of the denotata (though the status may be influenced by these properties).

The mass/count distinction is essentially the distinction between those nouns which can be explicitly counted by using numeral modifiers, such as *girl*, and those which cannot such as *mud.* This is demonstrated in (1):

(1) a. *three girls,*
b.**three muds*
c. *three kilos of mud*,
d. *three buckets of mud*.

*Girl* can be directly modified and thus counted by the numeral modifier *three*, and is called a **count noun**, while *mud* can only be counted via a classifier expression like *kilo* or *bucket*, and is called a **mass noun**. Classifiers may be individuating or they may be non-individuating measure phrases. On the pure measure reading of *bucket, three buckets of mud* denotes a quantity of mud, and is synonymous with *three bucketfuls of mud*. This is distinct from the individuating use, where (1d) refers to three actual buckets filled with mud as in *three buckets of mud were standing in a row on the wall.* Landman 2004 discussed the different semantic properties of these two uses of classifier expressions.

The distinction illustrated in (1) is a genuine grammatical distinction with linguistic implications. Count nouns are associated with a number of different syntactic and morphological properties. The major ones are listed in I and II.

**I: properties of the noun**

a. count nouns occur with numeral determiners, mass nouns don't:
*three chairs, *three furnitures*
b. count nouns take plural morphology, mass nouns don't:
*chair/chairs, furniture/*furnitures*
c. count nouns do not normally occur with classifiers, mass nouns do:
**three pieces of chair/three pieces of furniture.*

**II. sensitivity of determiners to the mass/count distinction:**

a. some determiner select only count nouns:
*each/every/a book; several/few/many books; *every/*several furniture(s)*

b. some determiners select only for mass nouns:
*little/much water; *little/*much book(s)*

c. some determiners select for mass and plural nouns:
*a lot of /plenty of wine; a lot of/plenty of books; *a lot of/*plenty of book;*

d. some determiners are unrestricted;
*the/some book(s); the/some water;*

Not all these properties show up in all languages which distinguish between mass and count nouns. For example, in a language which does not mark plurality morphologically, the distinction indicated in (I.b) is irrelevant. Similarly, the selectional properties of determiners show up differently in different languages. In Hebrew, for example, *harbe* translates both *much* and *many* : thus we have *harbe melax* 'much salt', where *melax* is morphologically singular, and *harbe sfarim* "many books', where *sfarim* is marked as plural. Similarly, *kama* translates *how much* and *how many*, so we have *kama melax* "how much salt?" and *kama sfarim* "how many books?" (2c.d). However, only mass nouns occur with *harbe* without plural morphology, and so **harbe sefer* 'many/much book' is ungrammatical. Furthermore, the postnominal adjective *rav,* which also expresses 'a lot', is sensitive to the plural morphology. It modifies plural count nouns in which case it takes plural mophology and it modifies mass nouns, in which case it is singular. Thus we have *sfarim rabim*, "many books" vs *melax rav* "much salt" , However it too cannot modify singular count nouns and **sefer rav* 'much/many book' is ungramamtical. So while the identical diagnostics many not be available cross linguistically, the same kind of diagnostics show that the mass/ count distinction is a one which occurs in many languages.

The mass/count distinction is independent of the 'structure of matter'. Chierchia 1998a sums up many years of discussion by bringing five difference arguments in support of this claim:

(i) Entities which come in natural units of equal perceptual salience may differ in a single language as to whether they are mass or count e.g. *rice* is mass, while *lentil/lentils* is count.

(ii) Within a single language, there are pairs of synonyms, or near synonyms, where one of the pair is count and the other is mass.
English: *clothes/clothing*, *shoes/footwear*, *coins/change*, *carpets/carpeting*, *hair/hairs*, *rope/ropes, stone/stones.*
Dutch: *de meubel* (the piece of furniture)/*het meubilair* (the furniture).
Hebrew: *rehit/rihut (furniture) batzal/batzalim*
NB: These synonyms are of three kinds:
(a) *hair/hairs*, a single lexical item can be realised as mass or count,
(b) *carpeting/carpets*, two lexical items based on the same root are related by a morphological operation, one with a mass use and the other with a count use.
(c) *shoes/footwear,* there is no lexical relation between near synonyms where one is mass and the other count.

(iii) Count expressions in one language have mass near-synonyms in another.
English *chalk* is mass, but in Hebrew *giyr* is count.

(iv) Parallel count/mass synonyms, may be used differently cross linguistically:
English *hair/hairs* parallels Italian *capello/capelli*, but whereas in English you talk about cutting your hair using the mass noun, Italian uses the count plural

noun.(Chierchia 1998a):

(2) a. English: *I cut my hair* vs. **I cut my hairs*,
b. Italian: *Mi sono tagliato i capelli* (pl)/**capello*

(v) Some languages, such as Chinese, have only nouns which behave as mass expressions. Count usages require classifiers: e.g. Chinese *xíong* (bear) is a mass expression, and counting requires a classifier (from Krifka 1995):

(3) a. san zhi xíong
three classifier bear
"three bears" (objects)
b. san qún xíong
three herd bear
"three herds of bears"
c. san zhong xíong
three classifier bear
"three bears" (species)

These cross linguistic differences show that while the count/mass distinction is clearly influenced by the structure of matter, it is not taken over from it. So the question is what is at the root of the mass count distinction?

**2. Homogeneity and/or cumulativity cannot be at the root of the mass/count distinction.**

Attempts to distinguish between mass and count nouns focused for quite a long time on the downward and upward closure properties of the two kinds of nominals. The domain of mass nouns is both upwardly closed (cumulative) and downwardly closed (homogeneous or divisible) since, for example, water + water forms a (possibly discontinuous) entity also in the denotation of *water,* while a quantity of water split into two gives two quantities of stuff both in the denotation of water. (Divisibility is usually said to work down to minimal parts, and issue which I won't discuss here.) This contrasts with the count domain which is neither cumulative nor homogeneous. The sum of two entities in the denotation of *cup* cannot itself be in the denotation of *cup* (but only in the denotation of the plural *cups*), while splitting a cup into two more or less equal parts gives you two pieces neither of which is in the denotation *cup.* (It is possible to split a cup unequally into, say, a chip and the rest of the cup, and then larger part will probably still count as a cup, but this contrasts with *water*, where splitting a quantity of water gives you two quantities, **both of which** count as water. As Link 1983 and Landman 1989 point out, the predicate which parallels the mass noun in upward and downward closure properties is not the singular count noun, but the bare plural form of the count noun, which is also divisible down to minimal parts, namely the single individuals in the denotation of the singular count noun.

Link 1983 proposed a formal model to capture the difference between the mass and count domains. While explicitly not attempting to capture downward closure properties, for reasons that we will discuss below, he proposed a model which allowed linguists to capture the homogeneous/non-homogeneous, cumulative/non-cumulative distinction formally. Link proposed that both the mass and count domains have the structure of Boolean semi-lattices, with the essential difference that the mass domain is non-atomic, and the count domain is atomic. A count noun denotes a sets of elements that form the atoms of a Boolean semi lattice, and the lattice itself represents the denotation of the bare plural of the count noun. In other words, the denotation of a bare plural of a count noun is the closure of the set of atomic elements under the sum operation. The mass domain forms a non-atomic Boolean semi-lattice (Link is not committed as to whether it is or is not atomless), and the mass noun denotes the set of elements in the lattice. The two domains are separate, but related by a 'material part' relation. For example, *gold* is a mass term denoting quantities of stuff, and *ring* is a count term denoting a set of atomic individuals. If a specific ring a is made of gold, we assume that there is some quantity in the domain of *gold* y, such that y is a material part of a. This is given in (4a) ,where '◊' is Link's 'is a material part of ' relation. This enables Link to represent the statement that "this gold is old, but the ring that is made out of it is new" as in (4b):

(4) a. $\exists y\ GOLD(y) \wedge y \lozenge a$.
b. $\exists y\ GOLD(y) \wedge RING(a) \wedge y \lozenge a \wedge OLD(y) \wedge \neg\ OLD(a)$.

Although Link explicitly refuses to discuss downward closure properties, his representation of the mass and count domains in terms of non-atomic and atomic lattice structures has often been made into the stronger distinction between atomless and atomic lattice structures, which directly expresses the distinction between mass and count predicates in terms of cumulativity and homogeneity. Upward homogeneity , or cumulativity, is standardly defined as in (5), (the definition is based on Krifka 1998), while downward homogeneity (or simply homogeneity or divisibility) is defined as in (6):

(5) Cumulativity:
If P is cumulative if : $x \in P$ and $y \in P$ an d $\neg\, x = y$ then $x \sqcup y \in P$
"P is a cumulative predicate iff when x and y are distinct and both are in P, then their sum of x and y is also in P.

(6) Homogeneity (divisiveness):
If x is homogeneous then for any $x \in P$, and for any y: $y \sqsubseteq x \wedge \neg\, y = x \rightarrow y \in P$.
If $x \in P$ and y is a proper part of x then $y \in P$.

Count predicates, which are atomic, are obviously non-homogeneous, since the atoms of P, as the smallest elements in P, are precisely those elements which have no parts in P. Note that the definition in (6) is a strong form of homogeneity, which says that if P is homogeneous and x is in P then **any** part of x is also in P. This allows for the fact that 'cup' and 'cat' are not a homogeneous predicate despite the fact that a cup may have a chip broken out of it and still count as a cup, and a cat may lose an ear and the resulting ear-less entity (a part of the original cat entity) is still a cat. This is because while the chipped cup in still in the denotation of *cup,* the chip is not, and while the earless cat is still in *cat*, the complementary part, namely the ear, is not in the denotation of *cat*. So homogeneity or divisiveness, as defined in (6) is stronger than the property of being non-quantized.

It is easy to see that an atomless Boolean algebra represents the denotation of a predicate which is both cumulative and homogeneous. For any two elements in an atomless semi-lattice L, the join of those elements is also in L (cumulativity). Since the semi-lattice is non-atomic, i.e. is not constructed from minimal elements, any element is itself non-trivially the join of its parts. In the count domain, the singular count noun C denotes a set of atoms, i.e. the minimal elements of a semi-lattice. Thus the sum of two elements in C cannot by definition itself be in C. Since atoms are minimal elements, a predicate of atoms cannot denote a homogeneous property.

While the claim that homogeneity and cumulativity characterise mass nouns and not count nouns makes sense intuitively, it runs into problems almost immediately. First, predicates like *salt* or *rice* have atomic parts – the salt or rice atoms. The smallest salt entities and rice entities can be divided into parts which are not salt and rice, so *salt* and *rice* are not fully homogeneous predicates. This is the problem with downward closure which led Link to remain agnostic as to whether the semi-lattices representing the mass domain were atomless or merely non-atomic. The issue has been discussed extensively in Gillon (1992), Chierchia (1998a), and Landman (2006).

Second, not all mass nouns are intuitively homogeneous, in particular, the group of mass nouns which are sometimes called 'superordinates' or quasi-kind terms, such are *cutlery*(British)*/silverware* (US) or *furniture* are not homogeneous. If something is a spoon, then it is in the denotation of cutlery (silverware), but a piece of a spoon isn't (although possibly, if I am sorting modular pieces, a piece which can be made into a spoon is cutlery). Similarly, a leg of a chair is not usually furniture, and the screws which hold the leg to the seat of the chair are not furniture either, although they are parts of things which count as furniture. One response to this piece of criticism is that with these superordinate mass nouns, what counts as minimal parts is just much bigger. Chair legs shouldn't count as furniture because they are parts of minimal elements of furniture, just like hydrogen atoms are parts of minimal elements of water. Note, by the way, that whether superordinate nouns are mass or count is itself not predictable. There is no obvious reason why *fruit* is mass (in British English) and *vegetable(s)* is count, or why *furniture* is mass and *toy(s)* is count.

One way to maintain the idea that homogeneity is at the root of the mass/count distinction is to claim that while mass nouns are indifferent as to the homogeneity/non-homogeneity of their denotations, count nouns are non-homogeneous. But this cannot be the case since there is a third problem with defining the mass count distinction in terms of homogeneity. Crucially, there are count nouns which are homogeneous.

Homogeneous count nouns include nouns such as *fence, line, plane, sequence, twig,* and *rope.* These have been noticed in the literature at various times over the last twenty years. Mittwoch 1988 shows that entities in the denotation of *line* and *plane* have proper parts which themselves are lines and planes; Krifka 1992 points out that *sequence* and *twig* have proper parts which themselves count as a sequence or a twig; Gillon 1992 notes that we find the same thing with nouns which move between a mass and a count use, since one rope can be cut into many ropes, one stone can be broken into stones and so on. Rothstein 2004 shows that the phenomenon is even more general, and includes a wide variety of nouns including a group which patterns like *fence/wall/hedge,* nouns like *bouquet* and so on. Note crucially that the strong form of homogeneity holds here; it is not just that x has a proper part which is also P, but that x can be divided into two parts, both of which are in P (Gillon 1992). There have been fewer attempts to explain why these nouns are in fact count. Zucchi and White 2001 make some suggestions why such nominals in direct object position induce telic readings of accomplishment-headed VPs, but they do not discuss why the homogeneous head nouns themselves are count. [1]

Another issue which arises when trying to explain the mass/count distinction in terms of homogeneity is that homogeneity looks like a real world property and not a

[1] I make some suggestions about the semantics of these nouns in Rothstein 1999, 2004, but these are superseded by the analysis presented in this paper.

semantic property, and so doesn't capture the independence of the mass/count distinction from the structure of matter. *Cat* is not a homogeneous predicate, as we have seen, because a part of a cat is not a cat, but this is not a semantic property per se, but a reflection of our knowledge about what a cat is. Other predicates are 'sometimes homogeneous', depending on what entities are in there denotation in a particular model. For example, a part of a notepad may or may not be a notepad. If the original is one of those blocks with 500 pages joined by glue where you can tear off 50 page block to make a smaller notepad, then a part of a notepad is a notepad. If the notepad is bound and has a cover, then clearly this is not the case. It depends crucially on whether the original item in the world has a structure which determines what one unit is. But in a model in which only the first kind of notepad exists, then *notepad* is a homogeneous predicate. *Fence* in comparison, is homogeneous since the same piece of fencing can be analysed as one or several fences in the same situation under different criteria of individuation. If my house and yours adjoin each other, and both of us build a fence between our houses and the street which meet at a certain point, we could call it "a fence" or "two fences", depending on the context. (Is the town council charging for a permit to build fences, or giving tax deductions to those who build fences?)

Cumulativity doesn't fare any better as a defining property of the mass/count distinction. Mass nouns are indeed cumulative, since water +water gives an entity in the denotation of water. But while cat + cat is not in the denotation of *cat*, the sum of two fences could well be in the denotation of *fence* in a context in which the sum of fence parts can be treated as a singularity.

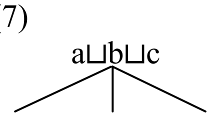
At this point we can conclude that neither homogeneity nor cumulativity can give the right characterisation of the distinction between mass and count nouns. This implies that the distinction also cannot be captured by saying that the count domain is atomic and the mass domain is non-atomic, and certainly not by the stronger proposal that the count domain is atomic and the mass domain atomless.

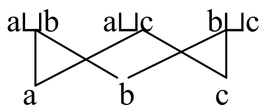
**3. The mass domain is an atomic domain.**

Gillon 1992, Chierchia 1998a,b, Landman 2006 all argue that the mass domain is atomic. Gillon and Chierchia argue that the structure of the denotations of mass nouns can be represented as atomic Boolean semi-lattices, while Landman argues that mass nouns are interpreted in an atomic domain, modelled by a Boolean lattice structure, although mass nouns themselves denote substructures defined on the lattices and these substructures are not themselves Boolean. The important observation that all papers make, and try to capture in terms of their structures, is that a mass expression and a count expression can denote the same collection of objects in the world. This can be seen from the fact that the same pile of stuff can be denoted by the count expression *the carpets* and the mass expression *the carpeting*. So the difference between mass and count expressions is not in the properties of the denotations themselves, but in how the nouns allow us to refer to them. For the purposes of exposition, I will adopt Chierchia's 1998a theory of mass nouns, although the argument that I am going to make in this paper can be made, with some changes, using any theory which assume that the mass domain is atomic.

We assume that the domain in which nominals find their denotation has the structure of a Boolean semi-lattice as in (7):

(7)






The individuals on the bottom line are the singularities, the atoms of the model, and the entities on the higher lines are the plural entities. The Boolean semi-lattice models the domain partially ordered by $\sqsubseteq$, the part-of relation, and closed under sum (or join) which we represent as '$\sqcup$' : Thus (8) holds:

(8) a. $a \sqsubseteq b \rightarrow a \sqcup b = b$.
b. Overlap: $\forall a,b\ [\ a\ O\ b \rightarrow \exists c\ \ [c \sqsubseteq a \wedge c \sqsubseteq b]]$
c. $\forall a, b\ [a \sqsubseteq b \wedge \neg a{=}b \rightarrow \exists c\ [a \sqcup c = b]]$.

In a standard account of the singular/plural distinction (Link 1983, Landman 1989), the structure in (7) gives the model of the count domain. The singular count noun denotes the set of atoms, or bottom elements of the semi-lattice, in our case the set {a,b,c} while the denotation of the plural gives the set of atoms closed under sum, i.e. the set of elements in the structure in (7) {a,b,c, a⊔b, a⊔c, b⊔c, a⊔b⊔c}. (In fact, Chierchia's account is slightly different: he defines the denotation of the singular count noun as the set of atoms, in our case {a,b,c}, but he defines the denotation of the plural count noun as this set closed under sum, but minus the atoms which generate it, i.e. the set {a⊔b, a⊔c, b⊔c, a⊔b⊔c}. But, we can adopt Chierchia's account of mass nouns without assuming his account of plural count nouns. See footnote 2 below.)

The crucial part of Chierchia's analysis is the proposal that mass nouns also denote sets of elements structured as in (7). Chierchia argues that mass terms are grammatically singular, but lexically plural; "mass nouns come out of the lexicon with plurality already built in, and … that is the only way they differ from count nouns". This means that while a grammatically singular count noun denotes a set of atoms, and the plural of the count noun denotes that set closed under the sum operation, a grammatically singular mass noun denotes "the closure under sum of a set of atoms".[2] Suppose the predicate *piece of furniture* denoted the set in (9a), and the plural of that predicate denotes the plural set in (9b). The mass term *furniture* as a lexical plural will have the denotation in (9c) although it is morphologically singular:

(9) a. *piece of furniture* $\rightarrow$ {$chair_1$, $chair_2$, $table_1$}
b. *pieces of furniture* $\rightarrow$ {$chair_1$, $chair_2$, $table_1$, $chair_1 \sqcup chair_2$, $chair_1 \sqcup table_1$, $chair_2 \sqcup table_1$, $chair_1 \sqcup chair_2 \sqcup table_1$, }
c. *furniture* $\rightarrow$ {$chair_1$, $chair_2$, $table_1$, $chair_1 \sqcup chair_2$, $chair_1 \sqcup table_1$, $chair_2 \sqcup table_1$, $chair_1 \sqcup chair_2 \sqcup table_1$, }

This means that Chierchia can explain why *that furniture* and *those pieces of furniture* (pointing at the same entities) clearly denote the same plurality of objects: the sum of

[2] As can be seen from (9), the plural of the count noun and the mass noun denote the same set. For Chierchia, the advantage of assuming that the plural noun denotes the set of plural elements **without** the atoms is that mass nouns and plural count nouns have different denotations. The mass noun will have the denotation in (9c), while *pieces of furniture* will denote the set { $chair_1 \sqcup chair_2$, $chair_1 \sqcup table_1$, $chair_2 \sqcup table_1$, $chair_1 \sqcup chair_2 \sqcup table_1$, }. We shall continue to adopt the conventional account of the denotations of plural predicates, and we will not let the synonymy illustrated in (9b/9c) disturb us. We will see shortly that the semantics for count nouns developed in this paper will end up making the denotations of the mass noun and the plural noun not necessarily identical.

entities in the denotation of *furniture* and *pieces of furniture* just are the same objects. The same holds for pairs such as *that carpeting/those carpets; that drapery (curtaining)/those drapes (curtains); that jewellery/those jewels*. Mass nouns and plurals such as carpeting and carpets thus have the same denotations, both of which can be represented as atomic Boolean lattices. However, there is a crucial difference between them. Count nouns make a set of atoms grammatically accessible (since there is a set denoting this set of atoms from which the plural set is compositionally generated), but in the mass domain the atoms are not grammatically accessible. Gillon 1992 shows the linguistic effects of this in an elegant minimal pair:

(10) a. The curtains and the carpets resemble each other.
  b. The curtaining and the carpeting resemble each other.

(10a) is ambiguous between the reading where each curtain resembles the other curtains and each carpet resembles the other carpet and the reading where the carpets, as a plurality resemble the curtains and the curtains the carpets. In (10b) only the second reading is available, presumably because in the mass domain the set of atoms in *curtaining* and *carpeting* are not accessible to the reciprocal operation.

In this paper, I follow Chierchia 1998a in treating mass nouns as denoting the closure under sum of the atomic elements in the denotation of a mass predicate. Since singular count nouns denote sets of atoms, both mass and count denotations are fomally generated by sets of atoms, and this means that there is no semantic representation of homogeneity in our domain, as Chierchia and Gillon want. Mass nouns are no more structurally homogeneous than plural count nouns . We will say no more about the structure of the mass domain since, instead of trying to get at the mass/count distinction by describing in what way mass nouns are special, we will concentrate instead on representing the structure of the denotations of **count nouns.**

**4. Evidence from Barner and Snedeker 2005**

Before giving an analysis of count nouns, we will look at the results of Barner and Snedeker (2005), who investigate experimentally the basis of quantity judgements by asking adults and children the question "Who has more X?" in three different sets of circumstances:

(a) where X is a mass substance term such as *mud*
(b) where X is a mass 'kind' term such as *furniture*
(c) where X is a 'flexible noun' such as *stone/stones, brick/bricks* etc

We will concern ourselves with the adult data. The questions were asked when the subjects of the experiments were presented with pictures of quantities of the relevant entity, and the results were as follows (the details of the experiments and the statistical analysis are given in the Barner and Snedeker 2005).

**Result I.** In the first situation, where the question was asked using mass-substance nouns, for example, "Who has more mud?", quantity judgements depended on overall quantity of stuff. One big heap of mud was consistently judged to be "more mud" than three small heaps of mud.

**Result II.** In the second situation, where the question was asked using mass-'kind' terms, for example, "Who has more furniture/silverware?" quantity judgements rely on number:

Three small pieces of silverware (cutlery) were judged to be more "silverware" than one big piece. Three small chairs were judged to be more "furniture" than one big chair, even when the volume or 'mass' of the single big chair was greater than the combined mass of the three small chairs. It is important that no context was given for the quantity judgement: the stimulus presented two sets of entities in a context-independent way.

**Result III.** In the third situation, which tested nouns which could have both a mass and count use, such as "Who has more stone/stones?", quantity judgements depended on the syntax of the noun. The stimulus was a picture of three small stones and one big stone, where the volume of the big stone was greater than the combined volumes of the three small stones. When the question was asked using a count noun, three small stones were judged to be more than one big stone, and when the question was asked using a mass noun, one big stone was judged to be more than three small stones.

Barner and Snedeker interpret this as follows: Result I and II show that some mass nouns denote individuals, while others don't.[3] A more precise statement might be that these results show that some mass nouns allow individuals to be salient for quantity judgements, and in these cases the quantity judgements are based on number of individuals and not overall mass. Result III shows that mass/count syntax influences the basis of quantity judgements. Even where the individual lumps of stone are salient, quantity judgements are by total mass and not by number when the noun is mass. So, although some mass nouns make individuals salient as a basis for quantity judgements, other mass nouns don't. Further more, Result III indicates that count nouns individuate, and that flexible terms must denote sets of individuals when they are used as count terms. The final point that Barner and Snedeker make is that there are two kinds of mass terms, those which they call 'substance-mass' such as *mud, salt* and *stone* on its mass reading, and those which denote heterogeneous classes of objects, kind terms. They call these 'object-mass' terms, and they include nouns such as *furniture* and *cutlery* (US: *silverware*); others have called them superordinates. These object-mass terms are those which rely on the salience of individuated entities for quantity judgements.

Barner and Snedeker argue that nouns like *furniture* appear in the lexicon marked [+individual], and that this is what allows quantity judgements to pay attention to number. They claim that "The conceptual apparatus associated with individuation is distinct from the linguistic feature which licenses its direct expression in the language" (p59). We can rephrase this observation as follows: in the case of object-mass terms, even when the salience of the individual allows quantity judgements in terms of implicit counting, you still cannot count grammatically. Even if in figure 1 you think that B has more furniture, based on the fact that B has three pieces of furniture and A only one piece, you still cannot say "B has three furnitures". This means that what is relevant for quantity judgements is not relevant for linguistic expressions of counting, in other words, **the conceptual apparatus of individuation and the grammatical mechanisms which allow direct reference individuals are distinct**. This means that the grammar of count nouns is not directly dependent on or derived from the conceptual salience of individual.

**5. Towards an account of the semantics of count nouns.**

At this stage we put together the two observations discussed in detail above:

[3] Barner and Snedeker 2005 suggest that this result is an argument against aspects of the Gillon/Chierchia type of analysis of mass nouns. I don't think this is correct, but the details of this argument don't concern us here.

(i) Observation 1: **Even when you can count the objects in the denotation of mass nouns implicitly because the units are salient (without an explicit context), you can't count grammatically.** The evidence for this is that while Barner and Snedeker's results (Barner and Snedeker 2005) show that the answer to "Who has more furniture?" was determined by comparing the cardinality of two sets of individuals, English still does not allow the statements in (11) as felicitous:

(11) a. #John has three furnitures.
b. # John has three furnitures more than Bill.

A second piece of evidence that individual units are salient even when nominals cannot be directly counted comes from adjectival modification. In Mandarin Chinese, bare nouns can never be directly counted but always require a classifier, as demonstrated in (12).

(12) a. liang ge pingguo
two Cl apple(s)
two apples

b. *liang pingguo
two apple(s)
two apples

Nonetheless, the individual unit is salient and can be directly modified. So while the modifier "big" can only modify the classifier in 'mass-type' nouns such as *water*, as in (13a), the same modifier can directly modify the noun when the noun is of the 'count-type' as in (13b).[4]

(13) a. liang da bei shui
two big Cl-cup water
"two big cups of water"
a'. *liang bei da shui
two Cl-cup big water
"two cups of big water"
b. liang ge da pingguo
two Cl big apple(s)
two big apples
c. wo mai le da pingguo
I buy perfective big apple(s)
I bought big apples

This shows that even though *pingguo* 'apple(s)' cannot be directly counted in Mandarin, the nominal denotes entities whose unit structure can be modified. Note that the same is true of *furniture* in English. While it sounds somewhat strange to talk of *the big furniture* , my informants accept (14) in plausible contexts:

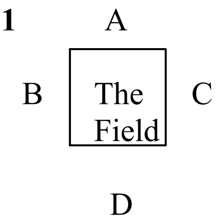
(14) a. The furniture in our house is big.
b. In a department store: "The big furniture is on the third floor."

[4] I thank Xuping Li for bringing these data to my attention. See discussion in Li 2007.

c. To movers who are emptying the house: "Take the big furniture down first please"

(ii) Observation 2. (Mittwoch 1988, Krifka 1992, Zucchi and White, 2001, Rothstein 2004) **Things that you can count grammatically don't necessarily come in individuated units, and are thus not inherently atomic.** As we saw, *twig, sequence, line, fence, wall*, *quantity of milk* and so on all rely on context to determine what one counts as one entity in the denotation of the singular predicate.
This has as a corollary the fact that when N is a count noun, the entities in its denotation can be directly counted even when what counts as a single unit is not uniquely determined. The example given in Rothstein 1999, 2004 is as follows. Suppose 4 farmers, A, B, C, and D build a fence each, as in Figure 1:

**Figure 1**




Then either each farmer built a fence, and there are four fences, one on each side of the field, or the field is enclosed by a fence, in which case there is only one fence around the field. Or suppose that I have a bouquet of flowers, and I split it and give half to my daughter and half to her best friend. Then, either there is a single bouquet which has been split, or each has a bouquet of flowers (albeit smaller than the original one). Similar examples can be constructed for count nouns such as *wall, twig, quantity of milk* and so on.

These two observations lead to the following conclusions:
Conclusion I. we cannot give a definition of mass/count which is dependent on the properties of the denotations of the expressions themselves.
Conclusion II. although there is a clear tendency for individual objects to be denoted by count nouns and "stuff" to be denoted by mass nouns, denoting inherently individuable entities is neither a necessary nor sufficient condition for being a count noun.
As a result of this we can conclude also that:
Conclusion III: the mass/count distinction can only be explained in terms of **how the expressions refer**, and not in terms of the things they refer to.

I propose treating count nouns as a mechanism for grammatical counting. We assume that grammatical counting requires a domain with specific **semantic** properties (not 'real-world' properties such as inherent individuability). We assume that the mass domain does not have such semantic properties.

We assume, following Chierchia, that the mass domain is modeled by a Boolean semi-lattice. The minimal elements in this lattice are (formal) atoms. The denotation of a mass noun $N_{mass}$ is the set of minimal atoms closed under sum. i.e. under the plural operation. So the denotation of a mass noun as it comes out of the lexical is a Boolean semi-lattice closed under meet and join. Following Chierchia, the atoms of the semi-lattice are contextually determined. For a noun like *furniture,* the minimal elements are usually (in the normal case) the single pieces of furniture, the individuals that Barner and

Snedeker have shown are relevant for quantity judgements. However, these minimal elements are not lexically accessible, since there is no lexical item which denotes exactly the set of minimal elements. Furthermore, these elements cannot be counted. (We will see why in a minute.) The choice of the set of atoms which generate the mass domain is context dependent, and the domain may be constructed on the basis of some set of minimal elements other than the set of pieces of furniture, for example the set of parts of modular build-it-yourself furniture.

For mass-substance nouns like *mud* we assume the minimal elements are the minimal relevant quantities of mud. As Chierchia argues, what the minimal elements are may be specified by context, or may be left vague and unspecified. This information need not be explicitly or implicitly specified. As with *furniture*, the set of minimal elements is not lexically accessible and is not countable.

My hypothesis is that the impossibility of counting is connected to the inherent vagueness and underspecificity of the criterion for choosing the set of atoms. I propose that grammatical counting requires an operation on a the denotation of a root nominal which picks out a set of elements each of which counts as one entity by some specified unit of measurement. These elements do not overlap. We call these elements Measured atoms, or M-ATOMs. Count nouns denote sets of M-ATOMs, and the M-ATOMs are the minimal atoms in the Boolean semi- lattice which is the denotation of plural count nouns. M-ATOMs are semantic atoms. They are atoms not just because they are the minimal elements generating a Boolean semi-lattice, but because they come with an explicit criterion for counting as a singularity and as such they are comparable and therefore available to grammatical operations such as counting. In other words:

- **Root nouns** denote sets of minimal elements in N closed under plurality. We call these $N_{root}$

- **Mass nouns** just are root nouns, i.e. $N_{mass} = N_{root.}$

- **Count nouns**, or $N_{count}$ are derived by applying the semantic operation M-ATOM to root nouns, $N_{root}$, and deriving a set of M-ATOMs in N. $N_{count}$ denotes a subset of $N_{root}$, a set of entities in $N_{root}$ each of which measures 1 according to some contextually fixed scale of measurement. So i.e. $N_{count} = OP(N_{root.})$. The content of OP is specified below.

Crucially, the unit of measurement need not be fixed, but may vary according to context, but must be recoverable from context. As we will see, with nouns such as *boy*, what counts as one boy is not context dependent, but with nouns such as *fence*, the choice of unit of measurement may vary from context to context. Thus in the situation illustrated in figure 1, whether there are four fences or one fence depends on the unit of measurement which the counting operation uses.

The operation of deriving $N_{count}$ is called M-ATOM, and it makes use of a standard measure function MEAS. MEAS is a function from (singular and plural) individuals into ordered pairs of where the first element is a natural number and the second element is a unit of measurement U. We assume that MEAS is additive, that is if $MEAS(x) = \langle n, U \rangle$ and $MEAS(y) = \langle m, U \rangle$ then $MEAS(x \sqcup y) = \langle m+n, U \rangle$ (Krifka 1998).

We use MEAS to define the counting operation, which we call M-ATOM. M-ATOM is a function of type $\langle\langle e,t\rangle\langle e,t\rangle\rangle$ from sets into sets which maps a set onto a subset of entities which count as one by a specified criterion. We assume that the output of the function is constrained to be a set of elements which are non-overlapping.

(15) M-ATOM(N) = $\lambda x.N(x) \wedge MEAS(x) = <1, U>$.
If $MEAS(x) = MEAS(y) = <1,U>$ and $\neg x=y$ , then $x \sqcap y = 0$.

The elements of M-ATOM(N) are the largest elements which count as one N-entity in the context. We will call them the M-ATOMs of N according to U, or for short, the M-ATOMs of N. It follows from the no overlap condition that iff an element x is in the output of the M-ATOM operation applied to N, then no proper part of it can also be in the set. Intuitively, the M-ATOMs are the largest elements which count as one U. Following and idea in Filip and Rothstein 2005, the M-ATOM operation can best be seen as a maximalisation operation, giving the set of maximal non-overlapping elements which count as 1 entity by a specified unit of measure. [5]

The difference between mass nouns and count nouns can then be represented as follows:

(16) Mass noun: $\lambda x. P(x)$
Count noun: $\lambda x. P(x) \wedge MEAS(x) = <1,U>$

With a predicate like *boy*, the value of U is determined by the meaning of the predicate itself. As we will see, the set of atoms of denotation of the root noun and the set of M-ATOMs in the denotation of the singular count predicate are the same set. We will call predicates like *boy* **naturally atomic**. When the predicate is not naturally atomic, then value of U is contextually determined.

The denotation of a count noun N is thus a set of M-ATOMS, i.e. a set of non-overlapping entities which count as one entity by some criterion of measurement. These M-ATOMs are elements which can be grammatically counted. Crucially, M-ATOMs, or semantic atoms, are not the minimal elements of the lattice structure which is the denotation of the root noun. A set of M-ATOMs need not even be a subset of the minimal elements in the denotation of the root N as we will see below. Instead they form a set of individuals which is summed by the pluralisation operation, and which forms the basis for the semi-lattice in the denotation of the plural count noun. Let us now look in detail at how this works.

## 6. How does this work?

**Mass nouns** are bare nouns. They are lexically plural, and thus denote the same as root nouns, i.e. $N_{mass}$ denotes the closure under sum of minimal parts of N. There is no specification of what the minimal parts are, and we assume, following Chierchia, this is determined context dependently, and may be vague or even not specified. When the mass noun is a noun such as *furniture* or *jewellery*, we assume that the object-like nature of the elements in the denotation of the predicate makes these objects salient as the minimal parts. They will therefore be available for quantity judgements, as Barner and Snedeker show. However, there is no operation which makes the minimal elements of N lexically accessible or grammatically accessible. The minimal elements of $N_{mass}$ are not lexically accessible since there is no lexical item which denotes them directly. They are not

[5] The idea that being an atom is being countable and this meanshaving the value "1", originates in Krifka 1989 and in the earliest versions of Landman's 2006 manuscript on mass nouns. The fomulation of the M-ATOM operation in this paper differs from both these versions since the M-ATOM operation crucially maps entities onto a pair <1,U>, rather than a just the number 1. Previous attempts to formulate how an atom in the count domain was picked out were presented in Rothstein 1999, 2001.

grammatically accessible since, as we saw above in example (10), they are not accessible to grammatical operations which require sets of semantic atoms. Therefore, even if the set of minimal elements of a mass noun is salient and is perceptually a set of individuals, these elements are not countable. In order for the minimal elements of $N_{mass}$ to be counted, a classifier must be used. The most neutral classifier is *unit of* and can be thought of as an explicit expression of the M-ATOM operation as in (17):

(17) I bought 10 units of furniture.

**Singular count nouns** are derived from bare nouns via an application of the M-ATOM operation**.** M-ATOM(N) is a set of semantic atoms derived from $N_{root.}$ Grammatical plurals denote the closure under sum of the set of M-ATOMs. There are two sorts of count nouns. Intuitively they are those where the count noun denotes things which are inherently individuable and those cases where it does not.
Nouns which denote things which are inherently individuable are those which are typically thought of as non-homogeneous. We call them **naturally atomic predicates.**

**Case 1: naturally atomic, non-homogeneous count nouns: *boy, pencil, etc***
These predicates are **naturally atomic**, by which we understand that the units of measurement are determined by the natural atomic structure of the stuff. What counts as one P is part of our knowledge of what a P is. So the value for U is supplied by the meaning of the predicate. Applying M-ATOM to *boy* gives us the expression in (18):

(18) $||BOY_{count}|| = \text{M-ATOM}(||BOY_{root}||)$
$= \lambda x..\ BOY(x) \wedge MEAS(x) = \langle 1, BOY \rangle$

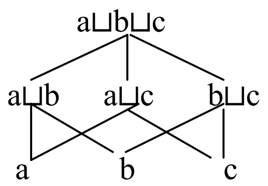
Note that the unit structure here is not dependent on size, but on some systematic property which defines what counts as a boy. Thus a giant preteenager and a small premature male baby each count as one instance of *boy* and together they make a plurality of boys with the cardinality 2.
We assume that in these cases the M-ATOM function is not context dependent and is the identity function on the set of minimal parts in the denotation of root noun.

**Case 2: homogeneous (and or cumulative) nouns: *fence, wall, sequence, quantity, bouquet.***
These are **not** naturally atomic, since the entities do not come in inherently individuated units. The unit of measurement must be contextually determined. The result of applying M-ATOM to *fence* is the expression in (19), where U is a variable to be contextually supplied:

(19) $||FENCE_{count}|| = \text{M-ATOM}(||FENCE_{root}||)$
$= \lambda x.\ FENCE(x) \wedge MEAS(x) = \langle 1,U \rangle$

Since U is contextually determined, it can have different values in different contexts. The set of M-ATOMs in the denotation of a noun like *fence* can , but need not be identical to the set of minimal elements in the denotation of the root noun.
Thus given a root denotation like (7), repeated here as (20), the set of M-ATOMs in $fence_{count}$ could be $\{a,b,c\}$ or $\{a, b\sqcup c\}$ or $\{a\sqcup b, c\}$ or $\{a\sqcup c,b\}$ or $\{a\sqcup b\sqcup c\}$.

(20)




The set of M-ATOMs in *fence*$_{count}$ need not be identical to the set of minimal elements in *fence*$_{root}$. A plausible context in which this might be the case is be where the minimal elements in the denotation of the root noun are pieces of fence in the possession of different individuals, but not all of these are big enough to count as actual fences in the given context. Note that the set denoted by M-ATOM(*fence*$_{root}$) does not necessarily cover the set of minimal fence parts. Some fence parts may not be part of an atomic fence because they are too small, and/or not connected to some bigger fence in the right way.

The denotation of the plural of *fence*$_{count}$ depends on the choice of M-ATOMs. If the set of M-ATOMs is identical to the set of minimal elements in the denotation of the root noun, then the plural *fences* will have the same denotation as the root noun, but if the choice of atoms is for example, $\{a, b \sqcup c\}$, then the plural of the noun will be that set closed under sum, i.e. $\{a, b \sqcup c, a \sqcup b \sqcup c\}$.

Note that this allows us to maintain Chierchia's account of mass nouns without either adopting his claim that singularities are not in the denotation of plural nouns nor being forced to the conclusion that plural count nouns and mass nouns necessarily have the same denotation. This is why: Assume a mass noun denotes a set P. The singular count noun will denote the set M- ATOM(P), and the plural count will denote *(M-ATOM(P)), or the set M-ATOM(P) closed under sum. This set of plural entities will be identical to P only when M-ATOM(P) is identical to the set of minimal elements of P.

Once we start thinking about it, the situations in which a count noun denotes a set of M-ATOMs where the choice of what counts as one unit is context dependent become more frequent:

(i) If I and my neighbour build adjoining walls, we may announce either "Together we built a wall in front of both our houses" or " We each built a wall in front of our houses".

(ii) If I have a bunch of flowers and I divide it into two and give a part of each to Dafna and her best friend Nomi, then either each has a bunch of flowers or each has half a bunch of flowers.

(iii) If a restaurant owner puts together tables a and b to make a bigger table $a \sqcup b$ and tables c and d to make another bigger table $c \sqcup d$, then a, b, c, and d no longer count as M-ATOMs in that context. There are either two tables or four tables in the restaurant, but no other possibility (i.e. not 6 and not 3).

This makes clear the contrast with the mass domain, where if I put sand together with sand, the parts and the sum of the parts fall under the denotation of *sand* simultaneously.

We are now in a position to explain Gillon's example, repeated from (10), more precisely:

(21) a. The curtains and the carpets resemble each other.
 b. The curtaining and the carpeting resemble each other.

As we saw above, Gillon pointed out that while *the carpets* and *the carpeting* may well denote the same piles of stuff, and similarly *the curtains* and *the curtaining*, the reciprocal can have only take as an antecedent the minimal elements in the denotation of the count noun and not the minimal elements in the denotation of the mass noun. If we assume that *each other* takes elements in a set of M-ATOMs as its antecedent, then this it is clear that the minimal elements in the denotation of the mass nouns are not possible antecedents for the anaphor, while the minimal elements in the denotation of the count nouns are. The mass noun can be a antecedent for the anaphor under its collective reading. This is explained as if we adopt Chierchia's 1998a suggestion that in order for the definite article to apply to a mass noun, the uniquely relevant sum of elements in the denotation of the mass noun must be raised to a group. A group is itself atomic according to some criterion of individuation (see Landman 1989) and is thus technically an M-ATOM and an appropriate antecedent for the anaphor.

Note also, that while *the carpets* and *the carpeting* may denote the same pile of material, the nouns *carpets* and *carpeting* do not necessarily have the same denotation, for reasons already explained above. *Carpeting* denotes a set of minimal carpet parts closed under sum, while *carpets* denotes a set of contextually determined carpet M-ATOMs closed under sum. If the set of minimal carpet parts and the set of carpet M-ATOMs is not identical, then the closure of the sets under sum will not be identical either.

We can sum up in the following way:

We assume that bare nouns are nominal roots, and that these are lexical plurals, where pluralisation is closure under sum of minimal parts, whatever these minimal parts are. Bare mass nouns are root nouns, and so they are born as lexical plurals, following Chierchia 1998. Singular count nouns are the result of applying the function M-ATOM to the root noun, and the operation yields a set of semantic atoms or M-ATOMS in N. Grammatical pluralisation, marked by the plural morpheme, is an operation on count denotations and gives the closure under sum of a set of M-ATOMs. So bare mass nouns such as *mud*, *water* and *furniture* just are root nouns. Derived mass nouns such as *fencing, carpeting, drapery* are derived from root nouns via a morphological operation and have the semantics of root nouns.

Count syntax forces us to interpret an N as denoting a set of M-ATOMs, i.e. count nouns are the result of M-ATOM($\|N_{root}\|$). The operation M-ATOM applies to what is essentially the mass domain and picks out a set of M-ATOMs according to an appropriate measure criterion. The mass domain is thus basic since count noun meanings are derived by applying M-ATOM to the mass/root denotation. Crucially, while both mass and count domains are formally atomic, since both mass and plural count nouns denote atomic Boolean semi-lattices, only the minimal elements in the count domain count as semantic atoms. The grammar of counting recognises only M-ATOMS or semantic atoms, as countable entities, and thus only count nouns denote elements which can be directly counted. Given Gillon's example in (10), the grammar of reciprocality has the same constraints. However, Barner and Snedeker show that quantity judgements which do not involve explicit counting are sensitive to natural atomicity as well as to the syntax of the mass/count distinction.

**7. Natural Atomicity.**

What has enabled us to formulate theory just outlined is the recognition of the concept 'natural atomicity', which is a property a predicate has if the elements in its denotation come in naturally individuable units. For a predicate to be naturally atomic is close to what Barner and Snedeker mean when they say that some mass predicates come with a feature [+individual]. However natural atomicity is not quite the same, and it is important to specify why. First, we do not assume that all count predicates are naturally atomic. Some are not, although probably most are. And the converse is also true: most mass predicates are not naturally atomic, but some are. A second more serious factor is that natural atomicity turns out not to be a feature, which can be assigned positively or negatively, but rather a gradable property which a predicate has to a some degree or another. To see why, let us try and give a formal definition of natural atomicity.

A natural way to try and define it is the following:

(22) A predicate is naturally atomic if the function M-ATOM($N_{root}$) is a constant function.

This will presumably be the case where M-ATOM($N_{root}$) is the identity function on minimal parts of $N_{root}$. These will include the count nouns where the U variable is specified by the predicate itself, as in (19). (Note that this function can in principle apply to any root noun, whether or not the language allows the noun a count realisation, so it can be used for a test as to whether a mass noun is naturally atomic too.)

Given this definition of naturally atomic, some things come out as naturally atomic. M-ATOM(*cup*) is probably a constant function, while M-ATOM(*fence)* is not. But there are other cases where we will get answers in terms of probabilities, rather than in terms of yes/no. *Foetus* looks naturally atomic, but there are rare cases of Siamese twins joined in such a way that it is not always clear whether there are two foetuses or one with a split upper body part, and we need to clarify what our criterion for one fetus is. Different people with different considerations may come to different conclusions, and thus the content of U is not a given. *Boy* looks naturally atomic, but (in addition to the Siamese twins problem, there are cases of children born with sexual characteristics which makes it difficult to specify whether or not they are in the denotation of *boy*. In these cases it will almost always be the case that M-ATOM($N_{root}$) is a constant function, but there will be rare cases when it isn't, although the degree of variability even in these cases will be very limited. In these cases it will not be possible to fill in the unit variable in the M-ATOM function with an intuitive concept of what counts as an individual child or boy. Instead the criterion of individuation will have to be made explicit, and it may well differ from context to context.

A different case is the noun *table.* Tables seems to come in inherently distinguishable units, but nonetheless, as we saw above, M-ATOM(*table)* is not a constant function but is context dependent. So while we can define a formal notion of natural atomicity as in (22), whether or not a predicate counts as naturally atomic is going to depend on the probability that (22) holds, i.e. on the probability that M-ATOM function is the identity function on the minimal parts of $N_{root}$. We may decide to assign a feature [± naturally atomic] to those predicates where the M-ATOM function is either (almost) always constant or frequently context dependent, but we will need to leave a large number of predicates (both count and mass) unspecified for the feature. It seems better to leave natural atomicity as a gradable property of predicates the degree of which is learned through experience, both experience based on interaction with objects and linguistic experience.

As mentioned earlier, the idea that count nouns involve an implicit measure function is not in itself new. Krifka 1989 proposes that count nouns are derived from abstract nominal predicates, and analyses count nouns as two place relations between numbers and entities. He takes as a model expressions in English such as *five head of cattle,* where *head of* instantiates a classifier function. He analyses the classifier as a measure function, where the unit of measure is dependent on the head noun. In *five head of cattle*, the noun *cattle* is interpreted as $\lambda x.CATTLE(x)$, a function applying to plural entities. The function is associated with a lattice structure L representing the set of individual cattle closed under sum. *Head of* introduces a measure function represented by NU (for Natural Unit), and *five head* thus denotes the measure function $\lambda P \lambda x.(P(x) \wedge$

$NU(P)(x) = 5$. This measure function, when applied to the denotation of *cattle*, yields the measure function associated with the namely which when applied to *cattle*, yields the function compatible with the lattice L, namely $\lambda x(CATTLE(x) \wedge NU(CATTLE)(x) = 5$, equivalently, the set of plural entities in the denotation of *cattle* which are sums of five individuals.

Krifka proposes that in count nouns the reference to a natural unit is built into the meaning of the head noun. Thus *cow* (as opposed to *cattle*) denotes a two place relation COW' between numbers and entities illustrated in (23), where the relation between the relation COW' and the abstract predicate COW is given in (23b):

(23) a. $\lambda n \lambda x.COW'(x,n)$,

b. $COW'(x,n) \leftrightarrow COW(x) \wedge NATURAL\ UNIT(COW)(x) = n$.

COW is in effect the denotation of $N_{root}$.

As in the account given here, Krifka's account makes countability the result of an implicit measure operation which is part of the meaning of a count noun. However, there are crucial differences. Krifka assumes that the implicit measure function measures in NU, or natural units of measurement, whereas I have argued that this is a only one option and that the units of measure can be context dependent and not natural at all. He further assumes that a relation such as (23b) can be defined for all count nouns, whereas I have argued that there are many count nouns for which this is not the case.

It follows from this that Krifka treats the measure operation as an instantiation of a generalized measure function from individuals to natural numbers. Sets of atoms are just one instance of the output of the measure function. *Cow* denotes the same set as *one cow,* namely $\lambda x.COW'(x,1)$, while *five cows* denotes $\lambda x.COW'(x,5)$ and the bare plural *cows* denotes$\lambda x.\exists n[COW'(x,n)]$. The plural measure functions apply directly to the meaning of the abstract predicate COW precisely because Krifka assumes that a count predicate is naturally atomic.

I have argued here in contrast that the function on $N_{root}$ is crucially a function deriving semantic atoms which may not be identical to the formal atoms generating the denotation of $N_{root}$. The operation from the denotation of root nouns to sets of M-ATOMs is characterised by functions of the form $\lambda x.N(x) \wedge MEAS(x) = \langle 1,U \rangle$. Since the value for U may vary, the set given by M-ATOM($N_{root}$) may differ from context to context. The plural operation will yield a different set depending on the set of M-ATOMs that it applies to. Similarly *five N* will yield different sets depending on which plural set it applies to. As we have seen in the discussion of nouns like *fence*, this is exactly the result we want. This is proof that counting pluralities must be a measure operation on the plural set which is a set of M-ATOMs closed under sum, and not an operation directly on the denotation of the root nominal.

## 8. Mandarin Chinese

The account we have given here of the semantics of the mass/count distinction extends naturally to languages which do not grammaticalise this distinction as a distinction between nominal heads. It is generally assumed that classifiers are needed to make all nouns countable. Thus *pingguo* "apple(s)" cannot be explicitly counted without a classifier, as we saw above.

(24) liang *(ge) pingguo
two Cl apple(s)

We give explicit semantic content to classifiers by assuming that while English-type languages allow the M-ATOM operation to be introduced implicitly, resulting in a count noun, Chinese-type languages require the M-ATOM operation to be introduced explicitly. Classifiers are the lexical expression of the M-ATOM operation, and different classifiers introduce different 'units' of measure, as we saw in (3) above. So in general ||Classifier (N)|| = M-ATOM($N_{root}$), with the classifier specifying the unit of measurement. In (3) above the classifier measured bears in terms of natural atomic units of bear, herds of bear and species of bear respectively.

We can go one stage further. Cheng and Sybesma (1998) show that there is a grammatical distinction between what they call mass classifiers and count classifiers. Count classifiers are those which Krifka 1989 analyses as classifiers denoting a measure function expressed by NU or Natural Units, as discussed above, or, in the language used here which denote an M-ATOM function where the unit of measure is dependent on the natural atomic structure of the entities denoted by the nominal. . Count classifiers are 'naturally atomic' in the sense that they denote (almost) constant functions from the minimal elements the denotation of the root noun to a set of M-ATOMs, and rely on natural properties of predicate to determine in a context free way what those minimal elements are.

The crucial fact of interest is that there are grammatical differences between 'count' classifiers' and mass classifiers. In particular, mass classifiers can occur followed by DE, while so-called count classifiers cannot.[6] The contrasts are given in (25-26):

(25) a. san bang (de) rou
three CL-pound DE meat
'three pounds of meat'

b. liang xiang (de) shu
two CL-box DE book
'two boxes of books'

(26) a. ba tou (*de) niu
eight CL-head DE cow
'eight cows'

b. shi zhang (*de) zhuozi
ten CL DE table
'ten tables'

Thus DE seems to follow only classifiers which are naturally atomic. This indicates that even languages which do not have a distinction between mass and count nouns may nonetheless find the concept of natural atomicity grammatically relevant, in the sense that there are grammatical operations which are sensitive to it. This is what we would expect if natural atomicity is a semantically relevant concept, i.e. a concept which is not itself linguistic, but which the grammar of the language makes use of, no matter whether the M-ATOM function is introduced implicitly or explicitly.

[6] I am indebted to my graduate student Xuping Li for bringing this data to my attention. Cheng and Sybesma suggest that there are other differences between mass and count classifiers too. A full discussion of their datat and of the relevance of natural atomicity to the grammar of Mandarin Chinese will appear as part of Xuping Li's Ph.D. dissertation.

## 9. Remaining issues.

In this section I discuss a number of remaining issues which are connected to the mass /count distinction.

(i) *Link's paradox: "The ring is new, but the gold in the ring is old".* Link 1983 discussed the apparent paradox of an entity that could fall under the denotation of a mass noun such as *gold,* and at the same time under the denotation of a count noun such as *ring*. Furthermore, the same (pretheoretic) entity could have apparently contradictory properties. For example it could be old gold but a new ring. Link suggests that this is because mass and count nouns have their denotations in different domains; mass predicates denote 'stuff', while count predicates denote individuals. An entity x in the mass domain could have the gold property and the old property, and the entity y in the count domain could be in the denotation of *ring* and *new.* Link argues that the two domains, the domain of stuff and individuals, are related by the 'constitutes' predicate, C, smsuch that x C y if and only if x is an entity in the mass domain and y is in the count domain and x is a material part of y. *This ring is new but the gold is old* would then have the representation in (27):

(27) a. This ring is new but the gold (it is made out of ) is old.
b. $\exists x\, [RING(x) \wedge NEW(x) \wedge \exists y[\, GOLD(y) \wedge OLD(y) \wedge y\ C\ x]]$

Since x and y are not the same entity, there is no contradiction in saying that one is old and other is new. However, this analysis is not allowed under the current account, since mass and count nouns have their denotations in the same domain. The same entity is thus a (possibly plural) entity in the denotation of *gold* and a singular entity in the denotation of *ring*, and thus has both the old and the new property simultaneously. The solution to this paradox has to be in a theory of intensional properties. The issue is discussed in Landman 1989, Chierchia 1984, and in a different context in Heim 1998. The basic idea is that ascription of properties is not directly to entities, but to entities presented under particular guises. Chierchia argues that although a single event can intuitively be described as a buying event and a selling event, some properties can be ascribed to it only under one description or guise (to use Heim's term). Thus the same event may be an eager buying event but a reluctant selling event. Similarly Landman 1989 argues that even if the judges and the hangmen are the same individuals, they may be have properties such as being professional or efficient or on strike as hangman but not as judges, as in (28):

(28) John is efficient as a judge but inefficient as a hangman.

Clearly this is what is going on here: the same entity may be old as gold but new as a ring without invoking a 'constitutes' relation. What makes it clear that this is an issue of intensionality and not of the relation between the mass count domain is that the problem illustrated in (27a) can be reproduced within a single domain. So if I melt down an old gold cup and make jewellery out of it, I can describe the resulting situation by (29):

(29) This jewellery is new, but the gold (it is made out of) is old.

Here both the entity denoted by *this jewellery* and the entity denoted by *the gold* are in the mass domain, and so cannot be related by Link's formal 'constitutes' relation, and yet the sentence is non-contradictory.

(ii) *Are count nouns independent lexical items or are they derived via syntactic type raising?* In principle there are two ways to think about deriving count nouns on the basis of the semantics which we have given. One possibility is that the M-ATOM operation applies in the word-derivation component, i.e. in the lexicon. Some nouns are thus entered into the lexicon as 'count'. Another possibility is that all lexical items are root nouns, and that count nouns are derived in the syntax via some sort of type raising operation. On this approach, *hair* is a unique unambiguous lexical items with a mass interpretation. When it occurs in the syntax with following a count determiner, then it raises to a count interpretation, i.e. the M-ATOM operation applies. A slightly different version of this approach is suggested in Sharvy 1978, who suggests that count nouns in English are in fact mass nouns which appear as the complement of null classifiers in contexts in which count interpretation is obligatory. On the first approach, certain nouns as learned as being 'count' and are entered in the mental lexicon as such , and as a consequence, they appear only in a count context. On the second approach, the context forces the interpretation on the nominal, and learning English requires learning that in the presence of indicators of count syntax, the M-ATOM operation must apply. A general discussion of the pros and cons of these two approaches is given in Pelletier and Schubert 1989.

Here are want to point out one very strong argument that nouns are lexically count, which can be formulated now that we have recognised that both *furniture* and *boy* are naturally atomic. If count nominals are derived only when the syntax forces a type-shifting operation, there should be no reason why a noun like *boy* should not be usable with mass syntactic indicators. It would then display the same kind of behaviour as *furniture*: it would be syntactically a mass noun, but would denote a set of naturally individuable entities. These expressions could not be directly counted, but when counting is not necessary, this shouldn't be a problem. Assuming that all nouns are lexically mass should allow (30b/d) on a par with (30a/c).

(30) a. There is now furniture in my house.
b. *There is now boy in my class.
c. There is a lot of furniture in my house now that the four chairs and two tables have been delivered.
d. There is a lot of boy in my class now that John, Bill and Peter have enrolled.

But (30b) and (30d) are ungrammatical, indicating that *boy* really is lexically a count expression, independent of the syntactic context. We

There is of course type shifting in the syntax, from count to mass (and from mass to count ) readings. These occur in (31) (with apologies for the example in (31b).

(31) a. After he had finished the job, there was bicycle all over the floor.
b. After the accident, there was boy all over the ground.

These are examples of what David Lewis calls the "Universal Grinder", discussed in some detail in Pelletier 1989 and Landman 1991 (along with the "Universal Packager" which shifts from mass to count interpretations). They are acceptable because the context indicates a mass syntactic environment for a count item, and this mismatch induces a type shift of the meaning of *boy* and *bicycle* from a count interpretation to a mass interpretation. Given the context, the interpretation ignores the natural atomicity of *boy* and *bicycle*, and imposes a mass denotation in which the minimal parts are not the individual boys and bicycles, but the some vague set of small boy-parts and bicycle-parts. But if *boy* and *bicycle* are inherently mass, then (30) and (31) should all be equally felicitous with the context favouring a set of natural atoms as the minimal elements in (30) an a set of natural-atom-parts as the set of minimal elements in (31). If we assume that *boy* and *bicycle* are lexically tagged as count expressions then the explanations are straightforward. (30b/d) are infelicitous because count nouns have been entered in a mass syntactic context. In (31), where the same thing has happened, the situation is saved by a type shifting operation where the count noun is shifted into a mass reading and assigned a new denotation as a consequence. This type shifting cannot apply in (30b/d) because the contextually appropriate set of minimal items in the mass interpretation would be identical to the original set of minimal elements in the count denotation (and also the root denotation). Constraints on simplicity rule out applying a type shifting operation to get as an output a meaning which is identical to the input meaning, since this would be using type shifting where a simple lexical item can convey the same meaning. (Chierchia 1998a in his discussion of existential quantification in nominals argues similarly that introducing an existential quantifier implicitly via type shifting is impossible if there is a lexical determiner which can introduces it.) Notice also that assuming that count nouns are specific a type of lexical item explains naturally how different languages can mark different nouns as count, since lexical derivational process are often idiosyncratic, while type shifting operations are not. If count nouns are derived via some type-shifting operation driven by the syntactic, it is difficult to explain why different languages allow this operation to apply to different subsets of nouns in parallel syntactic contexts.

(iii) *Quantity judgements.*

There is one more question, raised by Barner and Snedeker's results, which we can now answer. Barner and Snedeker 2005 show that with mass nouns like *furniture*, quantity judgements involve comparing individuals, whereas with 'flexible' terms like *stone*, the basis for comparison depends on whether the noun has count syntax or mass syntax. They suggest that this is because *furniture* but not *stone* is marked as [+individual], and thus three small chairs can be judged as "more furniture" than one big chair. Barner and Snedeker need this [± individual] feature to explain the contrast between *furniture* and *stone* since three small stones are never judged as "more stone" than one big one, but only as "more stones".

I have suggested here that the grammar does not use such a feature. Instead, quantity judgements pay attention to number of natural atoms, even when the syntax does not allow grammatical counting. We therefore need to explain why with expressions like *stone*, quantity judgements are made on the basis of the syntax of the noun and not on the basis of natural atomicity. If *Who has more furniture?* requires comparing numbers of naturally atomic pieces of furniture in the absence of count syntax, then why does *who has more stone?* require you to ignore natural atomicity in the same syntactic context? Since the three individual stones are salient in the context, one might think that the mass noun could use number to make the quantity judgement, but in fact this is never the case.

Our theory predicts Barner and Snedeker's results without recourse to labelling nouns like *furniture* [+individual]. We assume that predicates can be naturally atomic independent of whether they have mass or count syntax., and that quantity judgements which do not require grammatical expression of counting make use only of natural atomicity. But there is an obvious pragmatic explanation for why *who has more stone?*

requires ignoring natural atomicity. Assume (as we have argued above) that it is part of the knowledge of English that *stone* has a mass form and a count form. A question of the form "Who has more stones?" is an explicit request to have a quantity judgement evaluated on the basis of number. As a consequence, the question "Who has more stone", using the mass form will naturally be taken as a request to make an evaluation based on quantity, and ignore the naturally atomic stones. Note that it is the availability of both forms which makes us interpret the use of one form as a request for a particular kind of quantity judgement.

Notice that even with predicates like *furniture* which are naturally atomic to a relatively high degree, we are not always forced to take the individual pieces of furniture as entities relevant for making quantity judgements. Landman 2006 points out that in a context in which furniture is modular, the minimal parts are not the items or pieces of furniture but the modular parts. Thus if I have three chairs and you have a couch made of the identical parts, I can naturally say:

(32) We have the same furniture.

But the elements relevant for making the quantity judgements do need to stay constant through a single context. So if you and I have the same modular parts, but I have three chairs and you have a couch, I can either say (32) or I can say "I have more furniture than you", but I cannot say (33), although each conjunct separately may be true relative to a different analysis of minimal parts.

(33) #We have the same furniture but I have more than you M-ATOMs.

(iv) *Appendix: Excursus into correct counting:*

Counting is adding specified atomic units of M-ATOMs. We have argued that the units must be specified for each lexical item and are often context dependent. So how do we manage to count across kinds as in *Two boys and three girls/are five children*?
Our measure function is additive, i.e. $MEAS_U(x) = n$ and $MEAS_U(y) = m$ then $MEAS_U(x \sqcup y) = n+m$. Thus counting boys as boys is non-problematic.

(34) $MEAS_{BOY}(x) = m \wedge MEAS_{BOY}(x) = n \rightarrow MEAS_{BOY}(x \sqcup y) = m+n$

To count boys and girls as children we need a common measure. There must therefore be a constrain on counting:

(35) In counting M-ATOMs of P, $U_1$ can be substituted for $U_2$ iff
$\forall x \in P: \forall n\ [\ MEAS_{U1}(x) = MEAS_{U2}(x)]$

So for all elements in BOY, since counting them as boys or counting them as children gives the same value, we can use either unit.

Since $MEAS_{fence1}$ (x) does not necessarily give the same value as $MEAS_{fence2}$ (x), this constraint guarantees that when we count elements of a non-naturally atomic predicate we must do it according to a single individuating criterion or unit of measure.

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