Plural Predication and the Strongest Meaning Hypothesis

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Abstract

The *Strongest Meaning Hypothesis* of Dalrymple et al (1994,1998), which was originally proposed as a principle for the interpretation of reciprocals, is extended in this paper into a general principle of *plural predication*. This principle applies to complex predicates that are composed of lexical predicates that hold of atomic entities, and determines the pluralities in the extension of the predicate. The meaning of such a complex predicate is claimed to be the truth-conditionally strongest meaning that does not contradict lexical properties of the simple predicates it contains. Weak interpretations of reciprocals (as in *the books are stacked on top of each other*), plural predicate conjunction (e.g. *the books are old and new*) and 'atomic' distributivity in general are derived by a unified mechanism, which 'weakens' the basic universal meanings of strong reciprocals, boolean conjunction and quantification over atomic entities.

1 Introduction

In formal semantics, the common conception of the relationships between word meaning and sentence meaning is rather simple: words denote objects in a given model of discourse; sentences denote truth-values – or more complex intensional entities – that are compositionally computed from the sentence structure and the meanings of the words it contains. *Lexical Semantics* studies word meanings and the relations between them; *Compositional Semantics* studies the meaning composition process and the ways it is affected by the syntax. Most often, it is assumed that the compositional process is 'blind' to the meanings it manipulates. For instance, we assume that the meanings of the sentences *the blue car is fast* and *the grey horse is strong* are derived in precisely the same way, and the semantic differences between them are only a function of the different denotations of the words they contain.

While this elegant division of labor between lexical and compositional semantics is justified for most semantic needs, work by Dalrymple et al. (1994,1998) on reciprocal expressions implies that in certain cases, the architecture of the interface between lexical and compositional semantics may be more complex. In Dalrymple et al's proposal, reciprocal expressions such as *each other* and *one another* are multiply ambiguous. A principle that is called the *Strongest Meaning Hypothesis* (SMH) claims that in any given sentence, the meaning of the reciprocal is chosen according to the meanings of the items it combines with. The reciprocal is claimed to receive the strongest reading that does not lead to a contradiction with the lexical meanings of these items. This principle systematically accounts for some previously unexplained variations in the meaning of sentences with reciprocals.

The present paper proposes that Dalrymple et al's SMH should be used as a general principle of plural predication. First, it is observed that SMH-like effects are not restricted to plural predicates with reciprocals: similar effects appear with 'cumulative' interpretations of plural predicate conjunction, with transitive plural predicates and in combinations of these three construction. Using these observations, it is shown that the generality of the SMH opens the way for some simplifications in the theory of plurals. Instead of Dalrymple et al's assumption about the ambiguity of reciprocals, their meaning can be treated as unambiguously 'strong', while deriving weaker readings using the extended SMH. A similar strategy becomes possible also for conjunction and atomic distributivity operators. The conclusion is that the SMH implies a rather peculiar kind of ambiguity in natural language: unlike lexical or structural ambiguity, SMH-based ambiguities are not compositionally derived from the meanings of sub-constituents or from different modes of their composition, but from a general interpretation strategy of resolving vagueness with plural predication.

Section 2 introduces the relevant data and their account using a formulation of the SMH as a general 'weakening' process in plural sentences. Section 3 briefly discusses some 'non-boolean' phenomena in the interpretation of *singular* predicate conjunction, and argues that they are independent of the SMH. Section 4 proposes a formalization of the extended SMH.

2 Weakening in plural sentences and the extended SMH

This section first reviews Dalrymple et al's general treatment of reciprocals. A parallelism between the interpretation of reciprocals and the interpretation of plural predicate conjunction is pointed out. These facts lead to the proposed extended version of Dalrymple et al's Strongest Meaning Hypothesis. Further predictions of this principle are shown to be correct, especially in the area of transitive predicates and of the interactions between such predicates, reciprocity and conjunction. Some remaining problems and loose ends are discussed, and the weakening aspect of the SMH is compared with an alternative approach that assumes pragmatic strengthening.

2.1 Weak readings of reciprocals and the SMH

Dalrymple et al. show that the interpretation of reciprocal expressions like *each other* or *one another* is sensitive to the lexical choice of the predicate they combine with, henceforth the *reciprocated predicate*. Consider for instance the sentences in (1a) and (2a).

(1) a. The girls know each other.

b. ... #but Mary doesn't know Sue.

c. Every girl knows every other girl.

(2) a. The girls are standing on each other.

b. ... but Mary is not standing on Sue.

c. #Every girl is standing on every other girl.

Assume that *the girls* in both cases are Mary, Sue and Jane. Sentences (1a) and (1b) are contradictory. However, sentences (2a) and (2b) are not: they are both true in case Jane is standing on Sue, who is in turn standing on Mary. This contrast can be described by assuming that (1a) is equivalent to (1c) (but see some qualifications in subsection 2.4.3 below) while (2a) is not equivalent to (2c). The first interpretation of reciprocals is often referred to as *Strong Reciprocity*. It is formalized below as an operator *SR*, which applies to a two-place predicate R (=a relation between atomic entities) and generates a one-place predicate over sets A of atomic entities.[1]

(3) $SR = \lambda R.\lambda A.\forall x \in A \forall y \in A[x \neq y \rightarrow R(x, y)]$

A proper way to paraphrase sentence (2a) is by claiming that for each girl, one of two things holds: either she is standing on another girl or another girl is standing on her. This leads to an interpretation of the reciprocal that Dalrymple et al. call *Inclusive Alternative Ordering* (IAO), which is formalized below.

(4) $IAO = \lambda R.\lambda A.\forall x \in A \exists y \in A[x \neq y \wedge (R(x, y) \vee R(y, x))]$

Dalrymple et al. argue that in between the SR and the IAO analyses, reciprocal expressions may have a variety of readings that are stronger than IAO but weaker than SR. For the present purposes, let us ignore the details of these interpretations, and concentrate on the contrast between SR in (1a) and weaker reading such as IAO in (2a).[2]

[1] The exact ontology of plural individuals is not specified in this paper, since it is quite independent of the issues that are discussed here. I use standard set-theoretical notation such as $x \in A$ to express the statement that a singular individual x is part of a plural individual A. Another question that is ignored throughout this paper is the exact derivation of the meaning of the reciprocal, an issue that is addressed in detail in Heim et al. (1991) and Beck (2000).

[2] See Dalrymple et al (1994,1998) and Beck (2000) for systematic accounts of various other readings with reciprocals.

To consider some more contrasts of this sort, the sentences in (5) below have readings that are derived using the SR reading of the reciprocals, but the sentences in (6) have weaker readings than SR (though not necessarily IAO).[3]

(5) a. The legislators refer to each other indirectly.
b. The people were familiar to one another.
c. These students respect each other.
d. The pirate, the robber and the thief noticed each other.

(6) a. The third-grade students gave each other measles.
b. The Boston pitchers sat alongside each other.
c. The men are training military optics at each other.
d. The pirates stared at each other.

Before Dalrymple et al.'s work, attempts to account for the semantics of reciprocals, notably Langendoen (1978), had tried to formulate the weakest interpretation reciprocals may get. Thus, cases like (2a) and (6a-d), where the interpretation of the reciprocal is rather 'permissive', were taken as an indication for its general meaning. This strategy leaves open the question of why in other cases, as in (1a) and (5a-d), the interpretation of the reciprocal is not so permissive. As Dalrymple et al. note, the answer to this question is unlikely to be some sort of pragmatic strengthening (by way of conversational implicature, for instance). More on this point will be said in subsection 2.7 below.

Dalrymple et al. propose that the variety of interpretations of sentences with reciprocals appears due to ambiguity of the reciprocal expression itself. Thus, for instance, in sentence (1a) the meaning of *each other* is SR, while in (2a) the same expression means IAO. The first part of Dalrymple et al's work is a characterization of the logical relationships between the different readings of reciprocals that they propose. The second part of their proposal is a principle that determines which one of these readings is realized in a given sentence. This principle, the *Strongest Meaning Hypothesis*, reads as follows.

(7) **The Strongest Meaning Hypothesis** (SMH): "A reciprocal sentence is interpreted as expressing the logically strongest candidate truth conditions which are not contradicted by known properties of the relation expressed by the reciprocal scope when restricted to the group argument." (from Dalrymple et al, 1994)

[3] Sentences (5a-b) and (6a-d) are simplified versions of examples by Dalrymple et al. that were taken from corpora of written English.

Let us exemplify the operation of the SMH in sentences (1a) and (2a). The strongest meaning possible for a reciprocal is *SR*. Sentence (1c) paraphrases the reading that this meaning generates for (1a). In this case the interpretation of the sentence is compatible with our (lexical) knowledge about the predicate *to know*. According to this knowledge (1c) is contingent – it *can* be true for any number of girls. The SMH claims that the strongest reading possible is also the attested one, and therefore in (1a) *each other* means strong reciprocity. In sentence (2a), however, strong reciprocity would result in the odd paraphrase (2c). This statement is by necessity false, given the semantic properties of the predicate *to stand (on)*.[4] For instance, the statement in (2c) requires that Mary is standing on Sue and that Sue is standing on Mary, which contradicts the anti-symmetry of the predicate *stand on*. As a result, the SMH expects the meaning of sentence (2a) to be weaker than statement (2c), as it is the case. The strongest reading of reciprocals in Dalrymple et al.'s system that does not contradict the properties of the predicate *stand on* is the IAO reading (which is, incidentally, also the weakest reading reciprocals get in their system). Hence, IAO is the attested reading of *each other* in sentence (2a). According to this approach, the denotation of the reciprocal is not fixed 'once and for all'. Rather, it changes according to knowledge on the possible denotations of the reciprocated predicate – that is, according to its lexical properties.

This intriguing connection between lexical knowledge and the logic of reciprocity provides for the first time an explicit and falsifiable principle that describes the way various interpretations of reciprocals can be obtained. However, there are two reservations that I would like to address:

1. The SMH is introduced as a construction-specific rule for reciprocals. One might expect such principle to have manifestations also in other linguistic contexts. Is it indeed the case?

2. Can the SMH mechanism be formulated without the unattractive ambiguity of reciprocals that Dalrymple et al. postulate?

In what follows I will propose affirmative answers to both questions. In fact, it will be shown that they can be viewed as two sides of the same coin: once we recognize the similarity between the behavior of reciprocals and plural predicates in general, it becomes possible to generalize the SMH in such a way that does away with the ambiguity of reciprocals in Dalrymple et al.'s proposal.

[4]Of course, the compositional analysis of sentence (2a) should involve the semantics of the preposition *on* and the PP it heads. To keep the exposition of the SMH clear, I ignore this complication and treat the non-constituent string *stand on* as a lexical predicate.

2.2 Weak readings of predicate conjunction

The familiar semantic analysis of coordination in Keenan and Faltz (1985) and Partee and Rooth (1983) assumes that the conjunction *and* is cross-categorially 'boolean' or 'intersective'. In Partee and Rooth's formulation, the cross-categorial meaning of *and* is recursively derived from its standard analysis as propositional conjunction using the following definition.

(8) $[\![and]\!] = \sqcap_{\tau(\tau\tau)} = \begin{cases} \wedge_{t(tt)} & \text{if } \tau = t \\ \lambda X_\tau.\lambda Y_\tau.\lambda Z_{\sigma_1}.X(Z) \sqcap_{\sigma_2(\sigma_2\sigma_2)} Y(Z) & \text{if } \tau = \sigma_1\sigma_2 \end{cases}$

This definition entails that *and* behaves according to the propositional truth table for conjunction when it appears as a sentential coordinator, and as set theoretical intersection when it appears as a coordinator of categories with other types 'ending with t'. For instance: the conjunction *tall and thin* denotes the intersection of the set of tall entities with the set of thin entities; *kissed and hugged* denotes the intersection of the relations denoted by the verbs *kiss* and *hug*, etc.

Although this general treatment of conjunction is simple and attractive, it has to face some serious challenges. Some of these problems are discussed in Krifka (1990), Lasersohn (1995) and Winter (1996,1998b,in press), among others. In the case of predicate conjunction, which is in the focus of the present paper, consider the following sentence in (11a).

(9) a. The birds are above the cloud and below the cloud.

b. #The birds are above the cloud and the birds are below the cloud.

c. Some of the birds are above the cloud and the other birds are below the cloud.

In the situation that is described in figure 1, sentence (9a) is true, but a 'strong' interpretation as in (9b), which is derived using standard boolean conjunction, is absurd. Sentence (9a) is correctly paraphrased by (9c), but it is not clear how the 'intersective' analysis of *and* in (8) can derive this interpretation.

Krifka (1990) proposes that examples such as (9a) show motivation for extending *non-boolean conjunction*, which is widely accepted for NPs, also to predicates and other categories. Krifka follows the preliminary proposal in Link (1983,1984), and employs a non-boolean definition of the denotation of predicate conjunction. According to this definition, the following rule holds.[5]

[5]This is the original definition that Link gives for the so-called 'hydra' construction (e.g. *the girl and boy who met at the coffee shop are friends of mine*). Unlike Link, Krifka does not fully define the denotation of *and* as predicate conjunction, but gives a more complicated *partial* cross-categorial semantics of conjunction. These differences between Link's proposal and Krifka's proposal are irrelevant for the purpose of this paper.

Figure 1: a cloud and a house with birds

(10) A conjunction P_1 *and* P_2 holds of an entity x iff x can be subdivided into x_1 and x_2 such that P_1 holds of x_1 and P_2 holds of x_2.

This definition, which is based on Link's Lattice theoretical analysis of plurals, correctly captures the meaning of sentence (9a) as paraphrased in (9c). More examples for such 'non-boolean' interpretation of predicate conjunction will be given as we go along. However, consider now sentence (11a) below, which is minimally different from sentence (9a).

(11)
a. The birds are above the house and below the cloud.
b. The birds are above the house and the birds are below the cloud.
c. Some of the birds are above the house and the other birds are below the cloud.

In figure 1, sentence (11a) is false, but the non-boolean analysis of the sentence as paraphrased in (11c) is true, since the set of four birds can be divided into a set of birds that are above the house and a set of birds that are below the cloud. By contrast, sentence (11b), which is equivalent to the analysis of (11a) that is derived by the boolean treatment of *and*, paraphrases sentence (11a) correctly.

We see that Link's and Krifka's non-boolean analysis of predicate conjunction gives a correct analysis for sentence (9a) but faces difficulties with (11a). By contrast, the 'intersective' analysis of conjunction, using the general scheme in (8), succeeds in (11a) but fails in (9a). The SMH gives us a clue for the origins of this contrast between the two sentences. In the sentence (9a), a 'strong' interpretation of conjunction and distributivity would mean that *every* bird is *both* above and below the cloud, which is of course absurd. However, in (11a), nothing is wrong with the 'strong' interpretation that claims that each bird is above the house and below the cloud, and this indeed is the preferred interpretation of the sentence.

A similar contrast exists between sentences (12a) and (12b) below, under the situation depicted in figure 2.

(12) a. The ducks are swimming and flying.

b. The ducks are swimming and quacking.

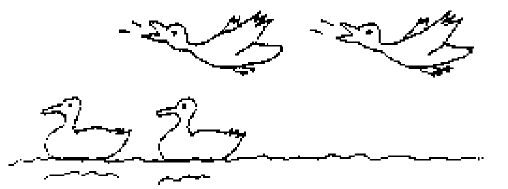

Figure 2: ducks

Sentence (12b) is falsified by the situation in figure 2. This is consistent with the acceptability of the 'boolean' paraphrase *the ducks are swimming and the ducks are quacking*. In sentence (12a), by contrast, such an assertion would contradict our knowledge that ducks cannot both swim and fly at the same time. The actual reading of sentence (12a) is accordingly weaker. The sentence can be paraphrased as claiming that some of the ducks are swimming and the other ducks are flying, which is true in the situation described in figure 2.

Other examples for weak interpretation of conjunctions with conflicting conjuncts, as opposed to strong interpretations of conjunctions with non-conflicting conjuncts, are given below.

(13) a. The books are old and new.

b. The books are old and interesting.

(14) a. The tall and short students participated in the meeting.

b. The tall and thin students participated in the meeting.

(15) a. They met several times before 1970 and after 1970.

b. They met several times before 1975 and after 1970.

Before moving on to the account of these weak interpretations using the SMH, it should be noted that problems of 'weak' predicate conjunction also appear in some cases of *singular* predicate conjunction. For instance, Krifka's example in (16a) is not equivalent to (16b).

(16) a. The flag is green and white.

b. The flag is green and the flag is white.

c. Part of the flag is green and the rest of it is white.

Krifka accordingly proposes to analyze sentence (16a) as in (16c), using the definition in (10). Such cases of weak interpretations of singular predicate conjunctions will be discussed in section 3, where it will be proposed that they follow from the conjunction of color predicates as *nominal* elements and not from the SMH itself.

2.3 The Extended SMH

The behavior of plural predicate conjunction supports the intuition behind the SMH also in cases of plural predication that do not involve reciprocity. When an intersective interpretation of a plural predicate conjunction is consistent with properties of the conjoined predicates, it is also the attested meaning of the conjunction. This is the case in (11a) and in the *b* examples in (12)-(15) above. However, when a boolean interpretation of *and* would lead to a statement that is inconsistent with the lexical properties of the conjoined predicates, the interpretation of the conjunction is weaker. This is the case in (9a) and in the *a* examples in (12)-(15). Therefore, it is reasonable to hypothesize that the 'weakening' effect of the SMH is not restricted to reciprocal expressions but is a more general property of plural predication. Let us therefore modify Dalrymple et al.'s hypothesis as follows.[6]

(17) **The (extended) Strongest Meaning Hypothesis**: A complex plural predicate with a meaning that is derived from one or more singular predicates using universal quantification is interpreted using the logically strongest truth conditions that are generated from its *basic universal meaning* and that are not contradicted by known properties of the singular predicate(s).

Let us define in more detail this proposed extension of the SMH, deferring some additional technicalities to section 4. We assume that when the semantics of a plural predicate leads to universal quantification over singularities, the result is subject to

[6]A similar revision of Dalrymple et al's SMH concerning reciprocals was independently proposed in Gardent and Konrad (2000). Gardent and Konrad implement their proposed revision within the KIMBA model generator (Konrad and Wolfram, 1999). Their proposal, however, concerns only reciprocal expressions and does not aim at extending the empirical coverage of the SMH in the same way as the present proposal.

weakening using the SMH. Universal quantification over singularities is common to the following traditional treatments of reciprocals, conjunction and distributivity.

(i) The meaning of a reciprocated predicate over collections is derived from the meaning of the corresponding binary relation R over singularities using the *strong reciprocity* (SR) operator:

$$\mathrm{SR}(R) \;=\; \lambda A.\forall x \in A\; \forall y \in A[x \neq y \rightarrow R(x,y)].$$

(ii) Boolean conjunction of two predicates P_1 and P_2 (over singularities or over pluralities) leads to the predicate $\lambda x.P_1(x) \wedge P_2(x)$, which can be presented using universal quantification over predicates:

$$P_1 \sqcap P_2 \;=\; \lambda x.\forall P \in \{P_1, P_2\}[P(x)].$$

(iii) The standard 'atomic' distributivity operator of Link (1983) maps a predicate P over atomic entities to a predicate over collections as follows:

$$P^D = \lambda A.\forall x[A(x) \rightarrow P(x)]$$

Note that we do not have to assume that these are necessarily the only strategies for the interpretation of plural predicates using reciprocity, conjunction and distributivity. We only need to assume that these are among the formal strategies for computing the meaning of complex plural predicates. When these universal procedures apply, the SMH takes effect. The actual process of interpreting plural predicates may involve additional semantic strategies, some of which will be mentioned in more detail later in this section.[7]

To see how the SMH works using these assumptions, reconsider sentences (1a) and (2a), reproduced below as (18a) and (19a). The basic meanings that are generated by strong reciprocity for the main predicates in these sentences are represented in (18b) and (19b).

(18) a. The girls know each other.

b. $\lambda A.\forall x \in A\; \forall y \in A\; [x \neq y \rightarrow \mathbf{know'}(x,y)]$

(19) a. The girls are standing on each other.

b. $\lambda A.\forall x \in A\; \forall y \in A\; [x \neq y \rightarrow \mathbf{stand\_on'}(x,y)]$

The operation of the extended SMH can be intuitively described as follows. The predicates (18b) and (19b), instead of being treated as the ultimate readings of the reciprocated predicates in (18a) and (19a) (which in the second case would be wrong), are

[7]For more extensive analyses of non-universal strategies of reciprocity, see Sternefeld (1998) and Beck (2000). For an overview of 'non-boolean' approaches to conjunction, see Winter (in press). Schwarzschild (1996) extensively argues for non-universal distributivity, but see Winter (2000) for an alternative account of Schwarzschild's data.

treated as *schemes for weakening* using the SMH. In order to describe the weakening procedure it is convenient to look at a concrete model as in figure 3(a). In this graph a directed arc from x to y corresponds to a (knowing/standing on) relation between girl x and girl y. The situation in figure 3(a) makes both predicates (18b) and (19b) true for the set $\{\mathrm{Mary}, \mathrm{Sue}, \mathrm{Jane}\}$. The crucial point is that while this situation is possible given lexical properties of the predicate *to know*, it is an impossible state of affairs with the predicate *to stand on*. The revised SMH requires a graph with a *maximal number of arcs* that does not contradict the lexical properties of the predicate. Therefore, the SMH predicts that the situation in figure 3(a) verifies (18a) and any graph with a smaller number of arcs does not. However, for (19a) the graph in (a) contradicts lexical properties of the predicate *to stand on* (e.g. anti-symmetry). Thus, also graphs with a smaller number of arcs should do to verify (19a). For example, the graph in figure 3(b) does not contradict lexical properties of *to stand on* but any additional arc in it would. Thus, according to the SMH this situation verifies (19a), which is indeed the case. These graphical intuitions will be given a formal correlate in section 4. Note, that although the SMH is stated as a process on predicates, it is more convenient to illustrate its application as a process on whole sentences, since only its results for the actual argument of the predicate in the sentence matter. I will henceforth follow this convention, and state the results of the SMH at the sentential level only.

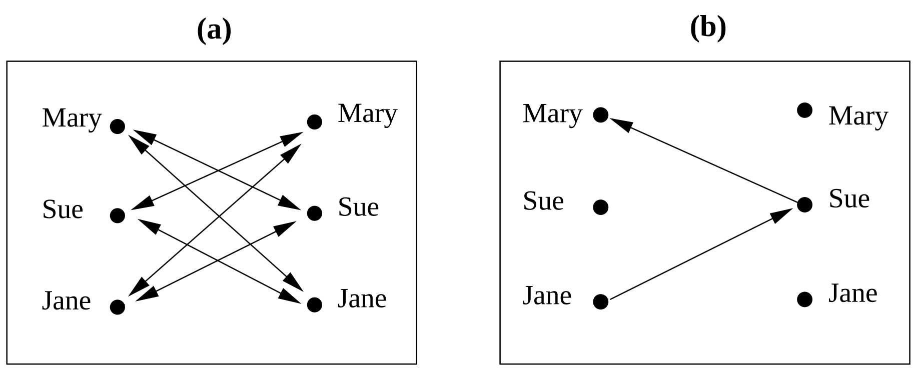

Figure 3: situations verifying (18a) and (19a)

Similar considerations to the one above hold in cases of conjunction such as (12b) and (12a), repeated below in (20a) and (21a), respectively. Given the formal assumptions above, we generate for these sentences the basic meanings in (20b) and (21b).

(20) a. The ducks are swimming and quacking.

b. $\forall x \in \mathbf{duck'}\ \ \forall P \in \{\mathbf{swim'}, \mathbf{quack'}\}\ [P(x)]$

(21) a. The ducks are swimming and flying.

b. $\forall x \in \mathbf{duck'}\ \ \forall P \in \{\mathbf{swim'}, \mathbf{fly'}\}\ [P(x)]$

Thus, in both (18b)-(19b) and (20b)-(21b) the propositions involve two universal quantifiers, in the latter case one of them quantifies over predicates. Consequently, the SMH works uniformly in both cases as a weakening procedure for the universal scheme. For instance, consider the situations in figure 4. The graph in (a), which attributes every duck both the swimming property and the quacking property, is possible given the lexical knowledge about these predicates. Therefore, the SMH expects this situation to satisfy sentence (20a), whereas a graph with any smaller number of arcs is expected to make the sentence false. In (21a), by contrast, a complete graph would contradict knowledge about the predicates *to swim* and *to fly*: a duck cannot swim and fly at the same time. The graph in (b) has a maximal number of arcs that does not contradict this trivial knowledge. Consequently, the SMH correctly predicts that also such a situation verifies (21a).

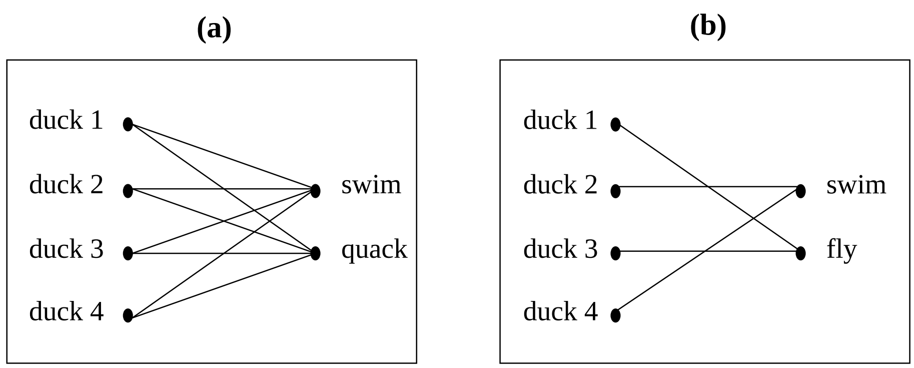

Figure 4: situations verifying (20a) and (21a)

In traditional boolean treatments of conjunction, sentences such as (21a), with a definite subject and a conjunctive predicate, are expected to be equivalent to the corresponding sentential conjunction in (22a).

(22) a. #The ducks are swimming and the ducks are flying.

b. $\forall x \in \mathbf{duck}' \, [\mathbf{swim}'(x)] \, \wedge \, \forall x \in \mathbf{duck}' \, [\mathbf{fly}'(x)]$

However, sentence (22a), unlike (21a), has a strange flavor: it implies that ducks can swim and fly at the same time. In the treatment that is proposed here, this contrast appears because the SMH applies at the predicate level. Thus, in (22a) it applies in each sentential conjunct separately. For these sentential conjuncts the SMH does not have any effect because their basic meanings do not independently violate any semantic property of the predicates that are involved. Therefore, the basic (incoherent) statement in (22b) is also the attested reading of (22a). In (21a), by contrast, predicate conjunction compositionally applies before predication and therefore also before the SMH applies. The resulting weakened meaning of the complex predicate leads to a coherent sentence meaning. To conclude, the difference between (21a) and (22a) is treated as a result of the interference of the SMH in the formal semantic predication process.

The informal discussion above suggests that the SMH can operate in the same way in cases of reciprocity and in cases of plural predicate conjunction, while predicting the semantic similarities observed between the two phenomena. In the following subsection we will see some further consequences of the general restatement of the SMH.

2.4 Further predictions of the SMH

The SMH in its new formulation in (17) is proposed as a general process of plural predication. This leads us to expect that 'weakening' of universal quantification over singular individuals should also appear with other complex plural predicates besides reciprocal and conjunctive predicates. In this subsection I argue that this is indeed the case when the basic reading of the plural predicate involves universal quantification over singular entities. However, various effects with plurals may generate basic readings which are different than the ones obtained by the simple formulation of distributivity and strong reciprocity that was assumed above. The implications of this complicating factor for the SMH are discussed.

2.4.1 Codistributivity and the SMH with transitive constructions

When we consider simple transitive constructions of the form NP-V-NP, we expect the SMH to show similar effects to its effects with reciprocals and predicate conjunctions. Universal quantification that is obtained by the simple atomic-unary version of a distributivity operator leads to universal forms where the SMH should in principle be operative. However, it often that plural NPs do not fully distribute but show a kind of 'polyadic distributivity', which is not subject to the SMH in its present statement. Two examples for such effects are sentence (23a), which may be interpreted as equivalent to (23b), and sentence (24a), which may be interpreted as equivalent to (24b).

(23) a. The policemen arrested the thieves.

b. Every policeman arrested a thief and every thief was arrested by a policeman.

(24) a. Mary and Sue are watching John and Bill (respectively).

b. Mary is watching John and Sue is watching Bill.

This kind of interpretation is sometimes referred to as *codistributivity* or *cumulativity*. A well-known proposal, put forward in Krifka (1992) and Schwarzschild (1991,1996), among others, is that the interpretation of plural predicates involves a *cover* or a *summation* mechanism responsible for such polyadic effects. An alternative proposal in Winter (2000) is that codistributivity effects are a result of the anaphoric properties of definites, and the (independent) general 'respectively' strategy of interpreting multiple conjunctions. Which of the two approaches is correct is irrelevant for our purposes here, but when testing the SMH it is important to eliminate codistributivity effects, since they lead to non-universal basic meanings. I assume that whatever mechanism leads to codistributivity, it applies prior to the process where the lexical predicate applies to the plural entities, and hence it does not partake in the weakening process of the SMH.

One way to avoid codistributivity effects is simply to make the codistributive interpretation false. For example, consider sentence (25) in situation (a) of figure 5.

(25) The cats are watching the dogs.

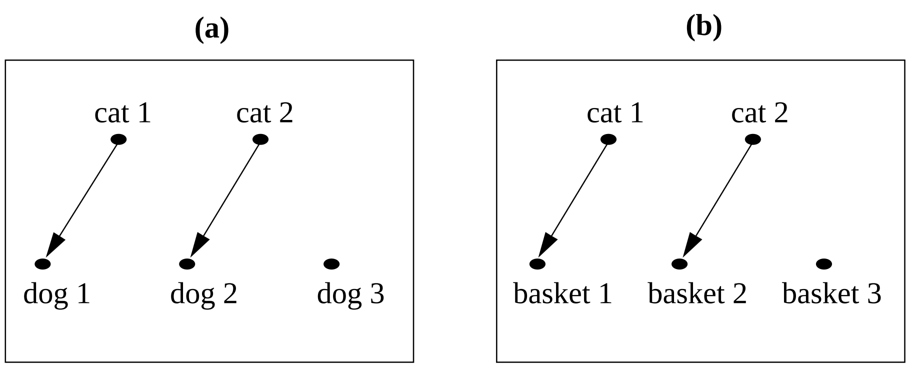

Figure 5: cats, dogs and baskets

It is hard to get a true codistributive reading of sentence (25) in this case, since no cat is watching dog 3.[8] By contrast, consider the following sentence.

(26) The cats are sitting in the baskets.

In figure 5(b), the same kind of situation as (a), sentence (26) is true although no cat is sitting in basket 3. The SMH in its extended formulation expects this sort of contrasts. A cat can watch more than one dog at the same time and therefore situation (a) in figure 5 does not contain a maximal number of watching relations given the lexical properties of the predicate. However, in situation (b) any additional 'sitting in' relation between a cat and a basket would require one cat to sit in two baskets at the same time. Therefore, according to the SMH this situation is expected to verify (26).

[8]Perhaps in special contexts that create dependency between each cat and 'its dog' this reading is possible. This is accounted for by the dependency analysis in Winter (2000).

Another piece of evidence in favor of the application of the SMH in transitive constructions comes from contrasts in the availability of the ’codistributive’ interpretation. The following sentences exemplify such a contrast.

(27) Mary and Sue saw John, Bill and George.

(28) Mary and Sue gave birth to John, Bill and George.

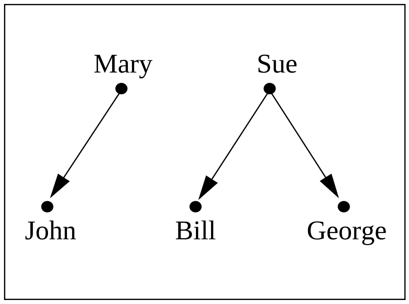

Figure 6: *see* vs. *give birth*

In a situation like the one described in figure 6, sentence (27) is judged false (or odd).[9] By contrast, sentence (28) is clearly true in the same situation. The situation in figure 6 does not contain a maximal number of seeing relations, given that it is possible that every woman saw every man. However, it is impossible that two or more women gave birth to the same child, and therefore figure 6 contains a maximal number of ’give birth’ relations with respect to sentence (28). Consequently, the SMH expects the contrast between (27) and (28) to appear.

2.4.2 SMH interactions

Effects of the SMH with reciprocals, conjunction and transitive constructions can interact. For example, sentence (29) involves ‘weak’ interpretations for both the conjunction and the reciprocal.

(29) The boys are sitting and standing on each other.

To see this, consider a situation in which John is sitting on George, who in turn is standing on Bill. Sentence (29) is true in this situation, although there is no boy who is both sitting and standing on another boy, and although neither the sitting relation

[9] In Winter (2000) it is argued that contrast between sentences like (27) and parallel sentences with definites (e.g. *the girls saw the boys*) is that codistributive interpretations with conjunctions are only a result of a ’respectively’ strategy, which is impossible when the number of conjuncts in each NP is different, as in (27). This is supported by the contrast between this sentence and *Mary and Sue saw John and Bill (respectively)*, which has a codistributive interpretation.

nor the standing relation satisfies strong reciprocity with respect to the boys. The SMH handles such examples correctly. A hyper-graph between couples of boys and sitting/standing relations is depicted in figure 7. Any additional triple-arc connecting two boys using one of the relations would violate properties of *to sit on* or *to stand on*. Thus, this situation verifies (29) according to the SMH. In section 4, the analysis of this example using the SMH is worked out formally.

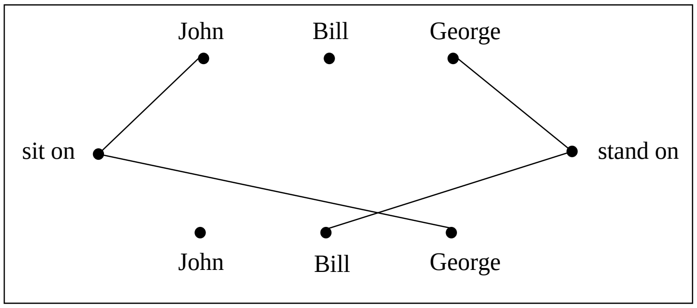

Figure 7: standing and sitting on each other

The following sentences exemplify other SMH interactions, this time between transitivity and conjunction, and between transitivity and reciprocity.

(30) Mary and John sent and received these letters.

(31) Mary and John sent these letters to each other.

Sentence (30) is true in case the noun phrase *these letters* refers to letters A and B, where letter A was sent by Mary and received by John and letter B was sent by John and received by Mary. Sentence (31), from Sternefeld (1997), is an example for weakening effects with respect to the reciprocal and the two other arguments of the predicate: (31) is true in the same situation mentioned above for (30). The SMH in its extended formulation accounts for these interactions in a similar way to the account of the interactions in (29). An interesting empirical puzzle is whether there are cases that show interactions of the three effects within a single sentence.

2.4.3 Collectivity and partial distributivity effects

The SMH is a principle that governs the derivation of meaning for predicates that range over sets (pluralities) from predicates that range over atoms (singularities). Reciprocals and plural predicate conjunctions are relatively easy test cases for the SMH because often there is strong evidence that these constructions must be interpreted using the singular version of the predicate, and they do not involve any collective interpretation. For instance, it is impossible to reduce sentence (6b), restated below as (32a), into any acceptable collective reading of a sentence such as (32b).

(32) a. The Boston pitchers sat alongside each other.

b. #The Boston pitchers sat alongside themselves.

In other words, in order to know whether (32a) is true, we must have access to properties of individual pitchers. In a similar way, to know if sentence (21a) (=*the ducks are swimming and flying*) is true, it is not enough to have a vague knowledge of whether the group of ducks is swimming and flying. It is the actions of individual ducks that matter for the evaluation of the sentence.

However, other cases of plural predication are notorious for their vagueness concerning the entailments for individual entities in the denotation of the plural NP. For instance, consider the two sentences below.

(33) a. The boys sang.

b. The boys lifted the pianos.

Sentence (33a) clearly does not require that every boy sang. Similarly, sentence (33b) does not require that every boy lifted every piano. This does not stand in opposition to the SMH because, unlike the cases of reciprocity (cf. (32a)) and conjunction (cf. (21a)), collectivity mechanisms may interfere with the interpretation of the sentences in (33). In these cases there are two possibilities for such collective interpretations:

1. *Direct predication over plural individuals*: Under this strategy, plural predicates apply directly to plural individuals (i-sums or sets).

2. *Indirect predication via 'impure atoms'*: In this strategy, following Link (1984) and Landman (1989), plural predicates can apply indirectly to plural individuals that are mapped to 'impure atoms' (singular entities). For instance, sentence (33a) can be interpreted as equivalent to the sentence *the group of boys sang*.

I will not deal here with the question of how to determine which of the two strategies (if any) is available for which plural predicate.[10] Rather, our interest here is only in how to eliminate such possibly confounding confounding processes, which make it harder to test the predictions of the SMH.

Yoon (1996) argues that certain plural predicates involve existential quantification over individuals rather than universal quantification or (direct or indirect) predication over pluralities. Yoon mentions pairs of adjectives such as *clean-dirty, dry-wet* and *closed-open*. The first predicate in each pair is called *total*, and Yoon argues that it involves universal quantification over singularities when its argument is a plural individual. The second predicates in these pairs are called *partial*, and they are argued to invoke existential quantification. For instance, according to Yoon, sentence (34a) is interpreted as equivalent to (34b), but (35a) is equivalent to (35b).

[10] See Winter (1998a) and Winter (in press) for a study of this question.

(34) a. The glasses are clean.

b. Every glass is clean.

(35) a. The glasses are dirty.

b. Some glasses are dirty.

If Yoon's claim is correct, then although the universal interpretation of (34a) is (in principle) subject to application of the SMH, this is not the case in sentences like (35a), where the basic meaning is not universal. Hence, the weak interpretation of sentence (35a) is its basic meaning, and not a result of the SMH. This may help to explain why sentences such as (36) below are unacceptable.

(36) #The glasses are clean and dirty.

According to Yoon's proposal, the only reading of this sentence is the following.

(37) $\forall x[\mathbf{glass'}(x) \rightarrow \mathbf{clean'}(x)] \wedge \exists y[\mathbf{glass'}(y) \wedge \mathbf{dirty'}(y)]$

Unlike pairs of predicates such as *swim* and *fly*, a conjunction of total and partial predicates such as *clean* and *dirty* does not form sentences with a meaning that is equivalent to a (doubly) universal formula as in (21b). As a result, the SMH cannot apply in these cases.

2.4.4 Partitioned and collective reciprocity

Roberts (1987:136-143) and Schwarzschild (1996:ch.6) (among others) argue that reciprocals are sensitive to contextual factors that impose "partitions" on the plural noun phrase. An example for such an effect is the following example from Beck (2000) (a modification of an example by Schwarzschild):

(38) The prisoners in the four corners of the room can see each other.

In a situation where there are opaque barriers that separate between the four corners of the room, this sentence can be easily judged as false, although the prisoners in each of the corners can see each other. This indicates that the sentence has an interpretation where the set of prisoners is "partitioned" into four groups, and the interpretation of the sentence is strong reciprocity with respect to these four groups:

(39) $\forall x \in \{g_1, g_2, g_3, g_4\} \forall y \in \{g_1, g_2, g_3, g_4\}[x \neq y \rightarrow \mathbf{can\_see'}(x, y)]$

I will not try to analyze the way in which such partitioned readings are derived. However, it is expected that the SMH should apply to these readings too. For instance, consider the following example.

(40) The balls in the four layers are stacked on top of each other.

The sentence can be used in a situation where there are four layers of balls, and the layers are stacked on top of each other. This of course requires that some layer or other is not stacked on top of any other layer. In contrast, sentence (38) does not allow a situation in which one of the groups of prisoners cannot see one of the other groups.

Such sensitivity to contextual partitions may explain why when large groups are involved, statements with plurals in general are rather vague with respect to contribution of singularities (independently of the vagueness effects resulting from collective predication that were discussed in subsection 2.4).

2.5 On the SMH and defaults in lexical semantics

There are some cases in which the strongest meaning hypothesis seems to be too strong. Namely, weakening occurs although it is not supposed to occur according to the SMH. Consider the following example from Philip (1996):

(41) The boys are tickling each other.

In the situation of figure 8(a), sentence (41) is true although the SMH (also in Dalrymple et al's formulation) expects it to be false, because it is *possible* for every boy to tickle *both* other boys in the picture.

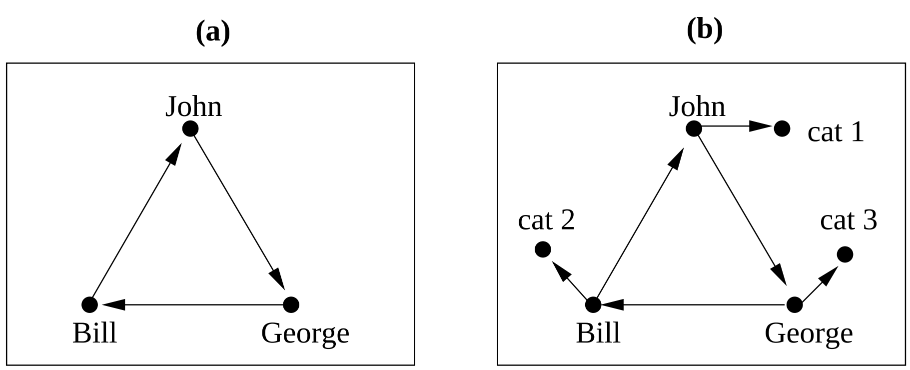

Figure 8: boys tickling each other

The reason for this potential counter-example to the SMH might be some gap in our lexical knowledge about predicates such as *to tickle*: although it can happen that a boy tickles more than one object, this might not be the default assumption about the predicate. In principle, it might be that the lexical knowledge about the predicate does require uniqueness of an object tickled by a person, and this would allow the SMH to account for the interpretation of (41). However, it is completely possible for John to tickle both George and Bill at the same time. Therefore, we must assume that the uniqueness default can be overridden: it is not as robust as the lexical knowledge we considered with predicates like *to stand on* or *to give birth to*. This line of reasoning expects that whenever the default assumption is overridden also the SMH ignores it. For example, in the situation in figure 8(b) every boy is tickling also a cat, in addition to the boy he is already tickling in (a). Consequently, we expect (41) to be interpreted differently in situation (b) than it is in (a): the sentence is expected to be less acceptable in (b), because in this case it is evident that every boy is not tickling the maximal number of boys he potentially can. Whether this prediction is borne out is not clear to me.

Mary Dalrymple (p.c.) mentions a similar problem to the present implementation of the SMH. Reconsider sentence (32a), restated below.

(42) The Boston pitchers sat alongside each other.

In Dalrymple et al's implementation of the SMH, there is no reading of *each other* that requires in (42) that the pitchers are sitting in a circle. Rather, a weaker analysis of the reciprocal that can make this sentence true is using the meaning called ‘intermediate reciprocity’, which correctly requires in (42) that the pitchers sit in a line. In the present proposal, since a circle configuration maximizes the number of *sit alongside* relations, this configuration is expected to be the only kind of situation that satisfies (42). Similarly to the case of sentence (41) above (which is problematic also for the SMH also in Dalrymple et al's version), I propose that the predicate *sit alongside* has a ‘default situation’ which presupposes a line configuration. As with the verb *tickle*, this may have empirical consequences: in situations that clearly override this defaults (e.g. when the pitchers sit in circle that includes also one basketball player), sentence (42) is expected to be unacceptable despite the fact that intermediate reciprocity is satisfied.

2.6 An open question

An opposite problem to the problems mentioned above appears in certain cases the SMH expects weakening to occur although actually it does not. Consider the following examples:

(43) #Mary and Sue/the women gave birth to each other. (after Sauerland (1994))

(44) #Mary and Sue/the women gave birth to John. (after Edwin Williams (p.c.))

In sentence (43) the SMH expects a weakened interpretation: *either Mary gave Birth to Sue or Sue gave birth to Mary*. This is clearly not the case because the oddness of the sentence indicates that it is a case of strong reciprocity: the implausible claim that Mary gave birth to Sue and vice versa. The same with (44): since it is impossible that two women gave birth to the same child, the SMH expects (44) to have a weak, plausible, interpretation: *either Mary or Sue gave birth to John*. This is incorrect. It seems that although the predicate *to give birth* can allow some weakening effects (cf.

(28)), there is a "lower bound" to the weakening that can take place: each member of the group argument should take part in at least one "giving birth" relation. Note that the contrast between sentences (27) and (28) the second argument in the relation *give birth to* is sensitive to the SMH. Why the subject argument does not show such sensitivity to the SMH is an open question.

2.7 Discussion: weakening or strengthening?

The SMH concept involves semantic *weakening* of a 'default' strong basic meaning. An opposite view, which is advocated in Langendoen (1978) among others, is to start with a weak meaning of plural predication and appeal to a strengthening principle symmetric to the SMH. For instance, it may be claimed that IAO (or another 'weak' analysis) is the basic meaning of reciprocals. In a sentence such as (18a), restated below, this reading is 'strengthened' to SR.

(45) The girls know each other.

In a similar way, it may be suggested that the meaning of *and* as predicate conjunction is essentially Link's and Krifka's 'weak' operator defined in (10). In sentence (20a), restated below as (46), the same strengthening principle is responsible for the 'strong' interpretation.

(46) The ducks are swimming and quacking.

Two theoretical points should be mentioned with respect to this potential alternative analysis. First, it is hard to generalize the 'weak' non-boolean reading of predicate conjunction to other categories besides predicates.[11] This is in contrast to the elegant cross-categorial definition of Partee and Rooth for boolean conjunction in (8). Second, as Dalrymple et al. point out, the 'strengthening' principle cannot be a pragmatic principle such as conversational implicature. This is because conversational implicatures are cancelable but the effects of SMH are not. For instance, sentence (47b) is a felicitous continuation of (47a), although the disjunction in (47a) is classically analyzed as invoking an 'exclusive *or*' implicature.

(47) a. John met Mary or Sue yesterday.
b. And maybe he even met them both.

By contrast, the semantic imports of strong reciprocity and boolean conjunction in sentences (45) and (46) are not cancelable. To see that, consider again the infelicity of

[11] Krifka (1990) is the only attempt I am aware of to take the non-boolean semantics of *and* as a point of departure for a cross-categorial definition. However, the proposed semantics is fairly complicated, and its consequences are not completely clear for types besides the types e, t and et, where the definitions of conjunction are stipulated *ad hoc*. For a technical critique of Krifka's proposal see Winter (1998b).

(1b) (=*but Mary doesn't know Sue*) as a continuation of (45), in a situation where the girls are Mary, Sue and Jane. Similarly, in a situation where the ducks, say, are Donald, Gerald, Robert and Lisa, the following sentence is not acceptable as a continuation of sentence (46).

(48) ...#but Donald Duck and Gerald Duck are not swimming and Robert Duck and Lisa Duck are not quacking.

Thus, if some sort of strengthening applies with reciprocals and plural predicate conjunctions then this strengthening is unlikely to be an instance of a general pragmatic principle and, like the SMH, it must be stipulated as a new principle at the interface between formal and lexical semantics.

Whether there is an *empirical* advantage to any of the strengthening/weakening strategies is not clear to me. A potential disadvantage of the present formulation of the SMH as a 'weakening' rule is that in principle, the only 'lower bound' of the weakening process is a tautological statement. For instance, Mary Dalrymple (p.c.) points out that sentence (49) below is expected to be equivalent under the present approach to sentence (21a), because the third predicate (*launching themselves into orbit around the sun*) cannot hold of any duck.

(49) #The ducks are swimming, flying, and launching themselves into orbit around the sun.

This prediction is not so harmful as it may look at first glance. In fact, similar effects appear under the standard semantic analysis of disjunction, and are assumed to be ruled out by pragmatic factors. Consider for instance the following sentences.

(50) a. #This book is a masterpiece or a camel.

b. This book is a masterpiece.

The weird sentence (50a) is standardly analyzed as semantically equivalent to (50b), under the (plausible) assumption that no book is a camel. However, if sentence (50a) is expressed by a speaker in order to convey the meaning of sentence (50b), then it is a violation of Grice's quantity maxim. I propose that sentence (49) is not interpreted in the same way as (21a) for a similar reason.

A related case where the proposed implementation of the SMH may seem inadequate is pointed out by Artstein (2001). Artstein argues that if the meaning of conjunction could be weakened indefinitely then sentence (51) should have had the same status as sentence (52).

(51) #The children are six and seven – in fact, they are all six.

(52) The children are six or seven – in fact, they are all six.

According to the SMH in its present formulation, sentence (51) should be equivalent to sentence (52). However, as in Dalrymple's example above, (51) is a very cumbersome way to make the statement in (52). The formal meaning of sentence (52) entails the interpretation of sentence (51) after application of a weakening principle. It is therefore plausible that a speaker who wants to emphasize the possibility that all the children are six would use sentence (52), and this makes (51) a misleading description of such a situation.

As an additional support for this pragmatic view on "plurality implications" with plural predicate conjunctions, consider the following example.

(53) All the participants from the Middle East and from the Far East should make sure they have visa.

This sentence does not become trivially true if in fact there turn out to be no participants (or only one participant) from the Middle East. Rather, the sentence still requires in such a situation that the participants from the Far East should make sure they have visa. This suggests that in this context the denotation of the conjunction *from the Middle East and from the Far East* does not require that the pluralities in its extension contain two or more elements from each region.

3 On 'weak' interpretations of singular predicate conjunction

The extended use of the SMH that was advocated in the previous section concentrates on plural predicate conjunction. However, as mentioned above, 'weak' interpretation also appear with *singular* conjunctions: reconsider Krifka's example (16a), which is repeated below.

(54) The flag is green and white.

If the conjunction *green and white* is analyzed as a simple predicate conjunction, then a boolean analysis expects (54) to be equivalent to the sentence *the flag is green and the flag is white*. This is of course problematic. Therefore, Krifka proposes that 'weak' interpretations of conjunction are needed in such cases, in an analogous way to their use with plural conjunctions. However, as Lasersohn (1995:282-3) points out, the 'weak' interpretation effect in (54) is exceptional in two respects. First, similar effects do not appear with many other singular predicates. For instance, sentence (55a) is equivalent to (55b) and not to (55c). Similar points hold for Lasersohn's examples (56) and (57).

(55) a. #The flag is small and big.

b. #The flag is small and the flag is big.

c. Part of the flag is small and the rest of it is big.

(56) #The car is cheap and expensive.

(57) #The piano is heavy and light.

This shows that a principle similar to the SMH does not apply to singular predicates: although the predicate conjuncts in (55a), (56) and (57) are contradictory, they are correctly analyzed using boolean *and* without any weakening effect. Thus, the analogy between (54) and sentences with plural predicate conjunction like *the flags are small and big* is only apparent (cf. (55a)).

Lasersohn observes that effects of 'weak' singular conjunction as in (54) are confined to color predicates and to material adjectives as in (58).

(58) John's coffee table is glass and chrome.

This observation leads Lasersohn to a reasonable hypothesis: what is common to color adjectives like *green* and *white* and to material adjectives like *glass* and *chrome* is that both kinds of items also function as nominals. This is illustrated by the following sentences.

(59) Green is my favorite color.

(60) Glass is my favorite supercooled liquid.

These nominals can of course be conjoined, as exemplified by the following sentences.

(61) Green and white are my favorite colors.

(62) Glass and chrome are my favorite materials.

Once this double use of color and material terms is recognized, it is plausible to assume that also in sentences like (54) and (58), the conjoined predicate can start as an NP conjunction. For instance, *green and white* may denote both in (54) and (61) the set of color names $\{g, w\}$. This plural individual can be interpreted "collectively" as a name for a color combination, which in English can appear in predicative positions as in (54) just like any color name. Of course, to treat the semantic relations between color names and color predicates would require a detailed account of nominalization phenomena, which I will not try to provide here. However, Lasersohn's approach to the problem of singular predicate conjunction is persuasive. If it is correct it means that conjunctions like *green and white* do not involve any weakening effect, and their interpretation is similar to the collective reading of nominal conjunctions of proper names such as *Mary and John*.[12]

[12] Whether such collective readings of nominals are obtained using 'boolean' conjunction or using 'non-boolean' conjunction is a separate issue, which is discussed in detail in Winter (in press).

4 Formalizing the extended SMH

In formalizing the SMH we first define a *normal form* for the basic meaning, relative to the tuple of n-ary predicates involved. This meaning is *weakened* using *lexical knowledge* (meaning postulates) about these predicates – conditions on their possible denotations. The underlined notions are defined below.

We employ the following notation:

1. For two natural numbers i and j, the notation $[i..j]$ stands for the set of natural numbers $\{s \in \mathbf{N} : i \leq s \leq j\}$.

2. Type $e^{(1)}(e^{(2)}(...(e^{(n)}t)...))$ of n-ary relations over singularities is abbreviated $e_{[1..n]}t$.

The basis for weakening using the SMH is restrictions on the lexical meanings of a series of predicates of the same arity, which is called *an* (m, n) *predicate tuple*. Officially:

Definition 1 An (m, n) *predicate tuple* is an m-tuple $\langle P_1, P_2, ..., P_m \rangle$ of n-ary relation constants over singularities, of type $e_{[1..n]}t$.

In order to use the SMH, we need to have lexical knowledge about the predicates in an (m, n) predicate tuple. This is an expression that is interpreted as an m-ary relation between n-ary relations between singularities. Officially:

Definition 2 The (m, n) *lexical knowledge* about an (m, n) predicate tuple $\overline{P}$ is an expression of type $(e_{[1..n]}t)^{(1)}(...(((e_{[1..n]}t)^{(m)})t)...)$, without free variables.

A predicate over pluralities that is derived from an (m, n) predicate tuple and can receive a normal form that involves universal quantification is subject to weakening using the SMH. This “normal universal form” is defined below.

Definition 3 Let $\mathcal{F}$ be a functional that maps any interpretation of an (m, n) predicate tuple $\overline{P} = \langle P_1, P_2, ..., P_m \rangle$ to a l-ary relation between pluralities, where $l \leq n$. A *normal universal form* of P relative to $\overline{P}$ is a formula φ of the form

$$\lambda B_1 ... \lambda B_l . \forall i \in [1..m] \ \forall x_1 \in A_1 \ \forall x_2 \in A_2 ... \forall x_n \in A_n \ [\psi(P_i, x_1, x_2, ..., x_n)]$$

that is interpreted as equivalent to $\mathcal{F}$ and satisfies:

1. $A_1, A_2, ..., A_n$ are predicate symbols from $\{B_1, B_2, ..., B_l\}$, where $A_1 = B_1$, $A_n = B_l$, and for all $i, j \in [1..n]$: if $i \leq j$ then $A_i = B_{i'}$ and $A_j = B_{j'}$, where $1 \leq i' \leq j' \leq l$.

2. ψ is an expression of type $(e_{[1..n]}t)(e_{[1..n]}t)$ with no free variables.

$A_1, ..., A_n$ and ψ are called *the parameters of* φ.

The weakening process itself is defined below as a process that changes the normal universal form of a predicate over pluralities using lexical knowledge about its (m, n) predicate tuple.

Definition 4 Let φ be a l-ary predicate over pluralities, in a normal universal form relative to an (m, n) predicate tuple $\overline{P} = \langle P_1, P_2, ..., P_m \rangle$, where $l \leq n$ and the parameters of φ are $A_1, ..., A_n$ and ψ. The following predicate over pluralities is the *SMH weakening* of φ relative to $\overline{P}$ and the lexical knowledge $\Theta_{\overline{P}}$:

$$\lambda B_1 ... \lambda B_l . \forall R_1 ... \forall R_m [\Theta_{\overline{P}}(R_1, ..., R_m) \rightarrow$$
$$|\{ \langle i, x_1, x_2, ..., x_n \rangle \in [1..m] \times A_1 \times A_2 \times ... \times A_n \ : \ \psi(P_i, x_1, x_2, ..., x_n) \}| \geq$$
$$|\{ \langle i, x_1, x_2, ..., x_n \rangle \in [1..m] \times A_1 \times A_2 \times ... \times A_n \ : \ \psi(R_i, x_1, x_2, ..., x_n) \}|]$$

In words: the SMH weakening of φ holds of the pluralities $B_1, ..., B_l$ iff the number of relations between the singularities in them that is obtained by the predicates in $\overline{P}$ is maximal relative to the lexical knowledge about these predicates.

To exemplify the operation of these definitions, consider again sentence (29), which is a rather general case due to the double weakening required in both the reciprocal and the conjunction. Strong reciprocity and boolean conjunction derive the following basic meaning for the matrix predicate in (29), in a $(2, 2)$ normal universal form:

(63) $\lambda B . \forall i \in \{1, 2\} \ \ \forall x_1 \in B \ \ \forall x_2 \in B \ \ [x_1 \neq x_2 \rightarrow P_i(x_1, x_2)]$
where $\overline{P} = \langle P_1, P_2 \rangle = \langle \mathbf{sit\_on}'_{e(et)}, \mathbf{stand\_on}'_{e(et)} \rangle$.

Thus, the parameters of this universal form are:

$$A_1 = A_2 = B$$

$$\psi = \lambda R_{e(et)} . \lambda y . \lambda z . y \neq z \rightarrow R(y, z)$$

The lexical knowledge $\Theta_{\overline{P}}$ should reflect the following facts about the meaning of the predicates $\mathbf{sit\_on}'$ and $\mathbf{stand\_on}'$: (i) They are mutually exclusive relations: if x is sitting on y then x is not standing on y. (ii) Their union describes a collection of mutually exclusive acyclic directed paths. Acyclicity means that if x_1 is sitting or standing on x_2, x_2 on x_3, ..., x_{n-1} on x_n, then x_n is neither sitting nor standing on x_1. The mutual exclusion of paths means that a person cannot sit or stand on more than one person and that two different persons cannot sit or stand on the same person.

If R_1 and R_2 are two relations, then the fact that they are mutually exclusive is simply expressed by $R_1 \cap R_2 = \emptyset$. We denote the required properties of the relation $R_1 \cup R_2$ by $\mathbf{acyclic}(R_1 \cup R_2)$ and $\mathbf{m\_ex\_path}(R_1 \cup R_2)$. Acyclicity of a relation R means that its transitive closure is anti-symmetric. Formally:

- The transitive closure of a relation R, $\overline{\mathbf{trans}}(R)$, is the relation defined by:

  $(\overline{\mathbf{trans}}(R))(x, y) \Leftrightarrow \exists x_1 ... \exists x_n [x_1 = x \wedge x_n = y \wedge R(x_1, x_2) \wedge R(x_2, x_3) \wedge ... \wedge R(x_{n-1}, x_n)]$.

- A relation R is anti-symmetric iff $\forall x \forall y [R(x, y) \rightarrow \neg R(y, x)]$.

- A relation R is acyclic iff $\overline{\mathbf{trans}}(R)$ is anti-symmetric.

The requirement about mutual exclusive paths of a relation R is formally defined by:

$\forall x \forall y \forall z [[(R(x, y) \wedge y \neq z) \rightarrow \neg R(x, z)] \ \wedge \ [(R(x, y) \wedge x \neq z) \rightarrow \neg R(z, y)]]$

Thus, we define the lexical knowledge $\Theta_{\overline{P}}$ for $\overline{P} = \langle \mathbf{sit\_on}', \mathbf{stand\_on}' \rangle$ as the following formula, denoting pairs of binary relations:

$\lambda R_1 . \lambda R_2 . R_1 \cap R_2 = \emptyset \wedge \mathbf{acyclic}(R_1 \cup R_2) \wedge \mathbf{m\_ex\_path}(R_1 \cup R_2)$

The formula given in (63) above is a normal universal form of the basic meaning of the matrix predicate in (29). Its SMH weakening relative to $\overline{P}$ and $\Theta_{\overline{P}}$ is given in (64).

(64) $\lambda B . \forall R_1 \forall R_2 [\Theta_{\overline{P}}(R_1, R_2) \rightarrow$
$|\{ \langle i, x_1, x_2 \rangle \in \{1, 2\} \times B \times B \ : \ x_1 \neq x_2 \rightarrow P_i(x_1, x_2) \}| \geq$
$|\{ \langle i, x_1, x_2 \rangle \in \{1, 2\} \times B \times B \ : \ x_1 \neq x_2 \rightarrow R_i(x_1, x_2) \}|]$

In words: a plurality B is in the extension of the weakened predicate iff for any two binary relations R_1, R_2 that are possible denotations of $\mathbf{sit\_on}'$ and $\mathbf{stand\_on}'$ respectively, the total number of pairs of elements $x_1, x_2 \in B$ such that $x_1 \neq x_2$ and one of the relations $\mathbf{sit\_on}'(x_1, x_2)$ and $\mathbf{stand\_on}'(x_1, x_2)$ holds, is greater or equal to the similar sum with R_1 and R_2.

Let us observe now that the situation in figure 7 above satisfies (64). The argument describing the set of boys is $\mathbf{boy}' = \{\mathbf{j}', \mathbf{b}', \mathbf{g}'\}$. Note first that in this situation:

$|\{ \langle i, x_1, x_2 \rangle \in \{1, 2\} \times \mathbf{boy}' \times \mathbf{boy}' \ : \ x_1 \neq x_2 \rightarrow P_i(x_1, x_2) \}| \ = \ 8.$

This is because the following tuples $\langle i, x_1, x_2 \rangle$ in $\{1, 2\} \times \mathbf{boy}' \times \mathbf{boy}'$ are the ones for which the formula $x_1 \neq x_2 \rightarrow P_i(x_1, x_2)$ holds:

$\langle 1, \mathbf{j}', \mathbf{j}' \rangle \ \langle 2, \mathbf{j}', \mathbf{j}' \rangle \ \langle 1, \mathbf{b}', \mathbf{b}' \rangle \ \langle 2, \mathbf{b}', \mathbf{b}' \rangle \ \langle 1, \mathbf{g}', \mathbf{g}' \rangle \ \langle 2, \mathbf{g}', \mathbf{g}' \rangle \ \langle 1, \mathbf{j}', \mathbf{g}' \rangle \ \langle 2, \mathbf{g}', \mathbf{b}' \rangle$.

Let us denote:

$s(R_1, R_2) \ = \ |\{ \langle i, x_1, x_2 \rangle \in \{1, 2\} \times \mathbf{boy}' \times \mathbf{boy}' \ : \ x_1 \neq x_2 \rightarrow R_i(x_1, x_2) \}|$

We want to show: $\forall R_1, R_2 [\Theta_{\overline{P}}(R_1, R_2) \ \rightarrow 8 \geq s(R_1, R_2)]$

This will show that the set of boys is in the extension of the weakened predicate.

The proof is by constructing R_1, R_2 in $\Theta_{\overline{P}}$ with maximal $s(R_1, R_2)$. Without loss of generality, assume that $R_1(\mathbf{j}', \mathbf{g}')$ holds. Let us denote $R_i^{\mathbf{b}} = R_i \cap (\mathbf{boy}' \times \mathbf{boy}')$. It is not hard to show by enumeration of cases that one of the following conditions must hold if R_1 and R_2 satisfy $s(R_1, R_2) \geq 8$ and $\langle R_1, R_2 \rangle \in \Theta_{\overline{P}}$:[13]

1. $R_1^{\mathbf{b}} = \{\langle \mathbf{j}', \mathbf{g}' \rangle\}, \quad R_2^{\mathbf{b}} = \{\langle \mathbf{g}', \mathbf{b}' \rangle\}$
2. $R_1^{\mathbf{b}} = \{\langle \mathbf{j}', \mathbf{g}' \rangle, \langle \mathbf{g}', \mathbf{b}' \rangle\}, \quad R_2^{\mathbf{b}} = \emptyset$
3. $R_1^{\mathbf{b}} = \{\langle \mathbf{j}', \mathbf{g}' \rangle\}, \quad R_2^{\mathbf{b}} = \{\langle \mathbf{b}', \mathbf{j}' \rangle\}$
4. $R_1^{\mathbf{b}} = \{\langle \mathbf{j}', \mathbf{g}' \rangle, \langle \mathbf{b}', \mathbf{j}' \rangle\}, \quad R_2^{\mathbf{b}} = \emptyset$

In other words: given that $R_1(\mathbf{j}', \mathbf{g}')$ holds, in order for R_1 and R_2 to satisfy $s(R_1, R_2) \geq 8$ without satisfying one of the four conditions above, they must violate the condition $\Theta_{\overline{P}}(R_1, R_2)$.
But for the four possibilities above $s(R_1, R_2) = 8$, which means that the predicate in (64) holds of the argument $\mathbf{boy}'$.

5 Conclusion

The study of the interactions between the lexical meaning of predicates and their compositional analysis is an area that has not gained much attention in the formal semantic literature. Logical approaches to natural language semantics, notably Montague Grammar, model a large part of the lexical knowledge as meaning postulates that are independent of the compositional process. According to the Strongest Meaning Hypothesis in its proposed formulation, lexical knowledge plays a major role in the compositional interpretation of plural predicates. In this proposal, the meaning of reciprocal and conjunctive items derives only the initial meaning of complex predicates, and the actual denotation of such predicates is also determined by lexical knowledge. Like Dalrymple et al, I believe that many of the puzzling data that challenge logical semantic theories of plurals can be better understood by considering the lexical semantics of predicates, which is likely to be of more relevance to the formal semantics of natural language than what most logical theories traditionally assumed.

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[13] For convenience, I ignore the possibility (that is also ruled out by lexical knowledge) that some boy is siting/standing on himself. Such situations do not matter for the counting consideration.

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References

Artstein, R. (2001). Conjunction weakening and morphological plurality. Unpublished ms., Rutgers University. To appear in proc. of WCCFL20.

Beck, S. (2000). Reciprocals are definites. Unpublished ms., University of Connecticut.

Dalrymple, M., Kanazawa, M., Kim, Y., Mchombo, S., and Peters, S. (1998). Reciprocal expressions and the concept of reciprocity. *Linguistics and Philosophy*, 21:159–210.

Dalrymple, M., Kanazawa, M., Mchombo, S., and Peters, S. (1994). What do reciprocals mean? In *Proceedings of Semantics and Linguistic Theory, SALT4*.

Gardent, C. and Konrad, K. (2000). Understanding each other. In *Proceedings of the First Annual Meeting of the North American Chapter of the Association for Computational Linguistics, Seattle*.

Heim, I., Lasnik, H., and May, R. (1991). Reciprocity and plurality. *Linguistic Inquiry*, 22:63–101.

Keenan, E. and Faltz, L. (1985). *Boolean Semantics for Natural Language*. D. Reidel, Dordrecht.

Konrad, K. and Wolfram, D. A. (1999). KIMBA, a model generator for many-valued first-order logics. In *Proceedings of the 16th International Conference on Automated Deduction, CADE99*.

Krifka, M. (1990). Boolean and non-boolean '*and*'. In Kálmán, L. and Pólos, L., editors, *Papers from the Second Symposium of Logic and Language*, Budapest. Akaemiai Kiado.

Krifka, M. (1992). Definite NPs aren't quantifiers. *Linguistic Inquiry*, 23:156–163.

Landman, F. (1989). Groups I & II. *Linguistics and Philosophy*, 12:559–605,723–744.

Langendoen, D. T. (1978). The logic of reciprocity. *Linguistic Inquiry*, 9:177–197.

Lasersohn, P. (1995). *Plurality, Conjunction and Events*. Kluwer, Dordrecht.

Link, G. (1983). The logical analysis of plurals and mass terms: a lattice theoretical approach. In Bauerle, R., Schwarze, C., and von Stechow, A., editors, *Meaning, Use and Interpretation of Language*. De Gruyter, Berlin.

Link, G. (1984). Hydras. on the logic of relative constructions with multiple heads. In Landman, F. and Veltman, F., editors, *Varaities of Formal Semantics*. Foris, Dordrecht.

Partee, B. and Rooth, M. (1983). Generalized conjunction and type ambiguity. In Bauerle, R., Schwarze, C., and von Stechow, A., editors, *Meaning, Use and Interpretation of Language*. De Gruyter, Berlin.

Philip, W. (1996). Children who know *each other*. Unpublished ms., UiL OTS, Utrecht University.

Roberts, C. (1987). *Modal Subordination, Anaphora, and Distributivity*. PhD thesis, University of Massachusetts at Amherst.

Sauerland, U. (1994). Codistributivity and reciprocals. In *Proceedings of the Western States Conference on Linguistics, WECOL94*.

Schwarzschild, R. (1991). *On the Meaning of Definite Plural Noun Phrases*. PhD thesis, University of Massachusetts at Amherst.

Schwarzschild, R. (1996). *Pluralities*. Kluwer, Dordrecht.

Sternefeld, W. (1997). Reciprocity and cumulative predication. In Hamm, F. and Hinrichs, E., editors, *Plurality and Quantification*. Kluwer, Dordrecht.

Sternefeld, W. (1998). Reciprocity and cumulative predication. *Natural Language Semantics*, 6:303–337.

Winter, Y. (1996). A unified semantic treatment of singular NP coordination. *Linguistics and Philosophy*, 19:337–391.

Winter, Y. (1998a). Atom predicates and set predicates: towards a general theory of plural quantification. In *Proceedings of Semantics and Linguistic Theory, SALT8*.

Winter, Y. (1998b). *Flexible Boolean Semantics: coordination, plurality and scope in natural language*.

PhD thesis, Utrecht University.

Winter, Y. (2000). Distributivity and dependency. *Natural Language Semantics*, 8:27–69.

Winter, Y. (2001). *Flexibility Principles in Boolean Semantics: coordination, plurality and scope in natural language*. MIT Press, Cambridge, Massachusetts. in press.

Yoon, Y. (1996). Total and partial predicates and the weak and strong interpretations. *Natural Language Semantics*, 4:217–236.