NOMINAL SCOPE IN SITUATION SEMANTICS

Roussanka Loukanova

Department of Math. Logic and Applications

Faculty of Mathematics and Computer Science

Sofia University, 1126 Sofia, Bulgaria

e-mail: rloukano@cs.indiana.edu

Abstract

This paper[1] introduces a semantical storage approach for representing nominal quantification in situation semantics. Quantificational determiners are treated as denoting binary relations, and their *domains* and *ranges* are defined. The *linguistic meaning* of an expression ϕ is given as a pair of its *quantificational storage* and *basis*. The storage contains the meanings of quantified NPs occurring in ϕ, while the basis represents the semantical structure of the result of the substitution of those NPs with parameters. Scope ambiguity is available when more than one quantifier is in the storage. A generalized quantificational rule moves some of the quantifiers out of the storage into the basis. There is a restriction that prohibites relevant free parameters from being left out of the binding scope. The storage is empty when there are no quantified NPs occurring in ϕ, or when there is enough linguistic or extra-linguistic information for resolving scope ambiguities.

1 Some Situation Theoretical Notations

A complete guide on the existing literature on situation theory and related topics is given by [Seligman and Moss 1997]. Quantification and anaphora in situation semantics are considered in great detail in [Gawron and Peters 1990]. The present approach differs from the later one in using the semantical storage and the lambda abstraction tools of situation theory to cope with the quantification in a computational mode. For another approach to compositional situation semantics that copes with quantification scope problems as well as with embedded beliefs, see

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[1]This paper was presented at the logic seminar at Indiana University, Bloomington, Indiana, in February, 1999. The idea of using a situational Cooper's storage originated during my research at Univ. of Oslo, Norway, 1989-90, where I was working in the extremely inspirational environment of the computational semantics group lead by Jens Erik Fenstad. I would like to thank Jon Barwise, Jens Erik Fenstad, Robin Cooper, Gregers Koch, and Larry Moss for their encouragement, attention and help. I am specially grateful to an anonymous referee who through strong criticism, encouragement, comments, and patience, made it possible for this work to be completed. From January till May 15, 2000, I am visiting: Linguistics - University of Minnesota, 190 Klaeber Court, 320-16th Avenue S.E., Minneapolis, MN 55455

[7]. For a detailed discussion of the linguistic arguments and background of an approach toward quantificational scope which is very close to the one presented in this paper, see [9], [10], [11] and [12]. It can be very well formalized by using the relational approach for semantics of quantitative determiners as proposed here. I shall assume some familiarity with situation theory. The following notations are used throughout the paper:

- $\lambda\xi\Theta(\xi)$ is the result of the abstraction over the parameter ξ in the situation theoretical object $\Theta(\xi)$.

- $\lambda\xi\Theta(\xi)$ is called a *type* in the special case of abstraction where $\Theta(\xi)$ is a proposition. To distinguish it from the general abstraction, I shall adopt the notation $[\xi/\Theta(\xi)]$ traditionally used in situation theory. The result of the application $[\xi/\Theta(\xi)](\alpha)$ is the proposition $\Theta(\alpha)$ obtained by the appropriate substitution of α for ξ in $\Theta(\xi)$.

- The proposition that an object α is of type σ is denoted by $(\sigma : \alpha)$. In the case when $\sigma = [\xi/\Theta(\xi)]$ and $\Theta(\xi)$ is a proposition, the new proposition $([\xi/\Theta(\xi)] : \alpha)$ is true iff the proposition $\Theta(\alpha)$ is true.

2 Quantificational Structures in Situation Semantics

The natural language quantification expressed by a simple sentence like EVERY STUDENT WALKS can be depicted by the following schemata:

(1)   NP/Quantifier

Determiner	Noun/QDomain	VP/QRange
every	*student*	*walks*
a	*student*	*is reading a book*
three	*men*	*are talking*

There are three different, but connected ways the scheme (1) to be interpreted. First, QDomain of the quantification is the set of the objects having the property denoted by the noun of the quantified NP, while **QRange** of the quantification is the set of objects satisfying the property denoted by the VP of the sentence. Then:

(2a) A quantitative **Determiner** denotes a quantitative relation between two sets, **QDomain**[2] and **QRange**, i.e. a particular **Determiner** specifies a quantity of objects from the **QDomain** that are also in **QRange**.

For example, the quantity expressed by the **Determiner** EVERY is all available objects from the **QDomain**. The suggestion in this work, as well as in [Farkas 1997a, b, c], is that (2a) is respected by all quantitative determiners like EVERY, A, SOME, FEW, MANY, MOST, ONE, TWO,

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[2]Sometimes what is called here QDomain is called **Restrictor**.

THREE, ... By this, the concept of a quantificational scope covers two separate semantical notions — the domain and the range of the particular quantification. There are two other ways we can interpret the quantification expressed in (1):

(2b) The **QRange** of a **Determiner** is the predicate expressed by the VP of the sentence and it is asserted for the specified by the **Determiner** quantity of representatives of the **QDomain** denoted by the noun (distributively or collectively).

(2c) The **Quantifier** expressed by a NP denotes a set of properties (i.e. its characteristic function). By a sentence $[[\alpha]_{NP}[\beta]_{VP}]_S$, the property denoted by the VP β is claimed to be in the set of the properties denoted by the NP α.

To unify the translations of the quantified NPs with those that are simple individual terms, Montague, see [8], chose the interpretation (2c) and went to the most significant generalization for a unified representation of the NPs as characteristic functions of sets of properties:

(1.1)

	Determiner	QDomain	QRange
(i)	*every*	[[STUDENT]]	[[WALKS]]
(ii)	$(\lambda Q \lambda P \forall x(Q\{x\} \to P\{x\}))$	($\hat{}$ student))	($\hat{}$ walk)
(iii)	$\underbrace{\forall x}_{Quantifier}$	$\underbrace{(\text{student}(x) \to \text{walks}(x))}_{\text{Scope}}$	

In the following sections I shall introduce a situation semantics for some quantificational noun expressions. It is associated with an interpretation function $\mathcal{F}$ defined for some lexical items and giving their semantical counterparts: $\mathcal{F}(\text{STUDENT})= student$, $\mathcal{F}(\text{WALK})= walk, \ldots$. In situation semantics, the determiners can be treated as denoting primitive relations between types of individuals, see [1], [3], [6] and [7]. For example, let *every, a, some, most, one, two, ...* be the primitive relations that are the values of the interpretation function $\mathcal{F}$ for the quantitative determiners EVERY, A, SOME, MOST, ONE, TWO, ..., respectively. Each of the quantificational relations comes with two argument roles that can be filled by types of individuals. These two argument roles shall be denoted by *QDomain* and *Qrange*. Thus in situation semantics, the propositional content of the linguistic meaning of the quantificational sentence EVERY STUDENT WALKS is expressed by the proposition:

$$(s \models \ll every, [x/(s_i \models \ll student, x, l_i; 1 \gg)],$$
$$[y/(s_j \models \ll walk, y, l_j; 1 \gg)]; 1 \gg).$$

The situation s is supporting the quantificational information, while s_j is where walking takes place. The situation s_i in which the noun $[\text{STUDENT}]_N$ is evaluated is called the *resource situation* of the NP. It might be that some of these three situations are the same, but they may be also different. The above proposition is true just in case every individual who is a student in the situation s_i is also an walker in the situation s_j. The quantificational scheme (1) becomes:

(1.2)

Quantifier

QRel	QDomain	QRange
$(s \models_{\ll} every,$	$[x/(s_i \models_{\ll} student, x, l_i; 1 \gg)],$	$[y/(s_j \models_{\ll} walk, y, l_j; 1 \gg)]; 1 \gg)$
$(s \models_{\ll} at\ least\ two,$	$[x/(s_i \models_{\ll} student, x, l_i; 1 \gg)],$	$[y/(s_j \models_{\ll} walk, y, l_j; 1 \gg)]; 1 \gg)$
$(s \models_{\ll} most,$	$[x/(s_i \models_{\ll} student, x, l_i; 1 \gg)],$	$[y/(s_j \models_{\ll} walk, y, l_j; 1 \gg)]; 1 \gg)$
$(s \models_{\ll} half\ of,$	$[x/(s_i \models_{\ll} student, x, l_i; 1 \gg)],$	$[y/(s_j \models_{\ll} walk, y, l_j; 1 \gg)]; 1 \gg)$

If we compare (1.1) and (1.2) we can see similarities in the corresponding quantificational patterns and their **QDomain** and **QRange**. In the same time they exhibit several important differences with respect to the syntax and semantics of the quantification in natural languages. The most significant difference is with respect to the level of the analysis. Lines (ii) and (iii) in (1.1) are syntactical representatives of the corresponding natural language sentence into IL, aiming to represent the corresponding semantics of the quantification. Line (1.1) (i) represents informally the semantics of a corresponding relational treatment of the determiner EVERY. There are strong intuitions about the meanings ⟦WALKS⟧ and ⟦STUDENT⟧ that they carry implicit information about situations where walking and being a student take place, and that those two situations might be different. Both of (ii) and (iii) lack to represent this important semantical information expressed by an utterance of the sentence EVERY STUDENT WALKS. While the situational $QDomain$ and $QRange$ types in (1.2) can be evaluated in different resource situations s_i and s_j, and either of them might be different from the quantificational situation s. Another difference between (1.1) and (1.2) is that there is no additional variable x attached to the determiner relation $every$ unlike the extra variable x in the quantifier $\forall x$. The relevant binding in (1.2) is achieved by the argument roles of $QDomain$ and $QRange$ types. The quantifier $\forall x$, together with the implication sign "$\rightarrow$", in the f.o.l., and in higher order IL, is introduced to express syntactically a purely semantical connection between the domain and the range of the quantification. Hence, even if there were no expressions involving quantificational scope ambiguities, the situation semantics would still have the advantages of being a theory bringing in finely grained and partial structural representations of the semantical objects as briefly pointed above. Another significant advantage is the possibility for introducing a context dependent semantical storage for computational dealing with the scope ambiguities at the semantical level. The translations into IL, like that in (1.1), for sentences with more than one quantifiers, can be obtained only for already in advance disambiguated English sentences by using extra-syntactical rules. For example, the sentence [EVERY LOGICIAN]$_1$ MET [A PHILOSOPHER]$_2$ would have to be first translated into one of the two of the following formulas:

$\exists y(\text{philosopher}(y) \wedge \forall x(\text{logician}(x) \rightarrow \text{meet}(x, y)));$

$\forall x(\text{logician}(x) \rightarrow \exists y(\text{philosopher}(y) \wedge \text{meet}(x, y))).$

The quantitative meaning of a determiner like EVERY, A, SOME, ONE, TWO, ... has two sides, invariant and varying, that are not in one-to-one correspondence to the surface syntax of the quantitative expressions. The invariant side of the lexical meanings of the quantitative determiners is that they denote two argument primitive quantificational relations between types of individuals. The varying part of the lexical meaning of a quantitative determiner is the partic-

ular quantity it expresses: *every, some, a, one, two, at least two, most, ...* For each determiner δ, the relation $\mathcal{F}(\delta)$ it denotes is satisfied by two types, T_1 and T_2, filling correspondingly the *QDomain* and the *QRange* roles, just in case that $\mathcal{F}(\delta)$ quantity of objects of type T_1 are also of type T_2. The quantity itself, $\mathcal{F}(\delta)$, i.e. *all, one, at least one, no, two, ...* is what varies from one determiner to another. The particular quantities can be expressed in situation semantics by formulating appropriate meaning constraints in the terms of the notion of an extension of a type. The last notion and the constraints for A and EVERY shall be formulated bellow (see [2]). For a simple sentence with only one quantitative NP which is the subject of the sentence, the relational meaning of the determiner closely corresponds to its syntactical role in the sentence: $[[[\delta]_{Det}[\alpha]_N]_{NP}[\beta]_{VP}]_S$. The two types T_1 and T_2 filling, correspondingly, the *QDomain* and the *QRange* roles of $\mathcal{F}(\delta)$, are the meanings of α and β, respectively. For more complex sentences the correspondence between the syntax and the main quantificational predication is not so straightforward.

Meaning Constraints for some Determiners

Let $T = [x/(s \models \sigma(x))]$, where s is a situation parameter or a particular situation, and $\sigma(x)$ is a parametric infon with x among its parameters. Let c be an assignment function for the parameters of T. The *extension* of the type T with respect to the assignment c is denoted by $\mathcal{E}(T, c)$ and is defined to be as follows:

$$\mathcal{E}(T, c) = \{c'(x)/ \text{ the proposition } (c(s) \models c'(\sigma(x))) \text{ is true, where } c' \text{ is}$$
$$\text{an assignment different from } c \text{ only possibly for } x\}.$$

Here $c'(\sigma(x))$ is the infon obtained from the infon $\sigma(x)$ after applying the substitution of the parameters occurring in $\sigma(x)$ defined by the assignment c'. The meaning constraints for the determiners a and *every* are as follows:

(C_a) The proposition $(s_q \models \ll a, T_1, T_2; 1 \gg)$ is true for a given assignment c of its parameters iff:

    (a) $c(s_q) \models \ll a, c(T_1), c(T_2); 1 \gg$, i.e. the situation $c(s_q)$ supports the quantificational infon, and

    (b) if the situation $c(s_q)$ is *informative*, then $\mathcal{E}(T_1, c) \bigcap \mathcal{E}(T_2, c) \neq \emptyset$.

(C_{every}) The proposition $(s_q \models \ll every, T_1, T_2; 1 \gg)$ is true for a given assignment c of its parameters iff:

    (a) $c(s_q) \models \ll every, c(T_1), c(T_2); 1 \gg$, i.e. the situation $c(s_q)$ supports the quantificational infon, and

    (b) if the situation $c(s_q)$ is *informative*, then $\mathcal{E}(T_1, c) \subseteq \mathcal{E}(T_2, c)$.

In the above statements the notion of an *informative situation*[3] is used in an intuitive way: a situation is *informative* just in case that the infons supported by it represent actual properties and relations between the objects. This condition for informativeness of $c(s_q)$ is needed because it might happen, for some reasons, that a situation $c(s_q)$ supports a quantificational infon without the two types to be really in the specified quantificational relation. For example, $c(s_q)$ might be a visual (or believe) situation which does not represent actual states of affairs. Generally, the propositional content of a quantification contributed by a determiner δ is:

(3.1) $(s \models \ll \mathcal{F}(\delta), QDomain : T_1, QRange : T_2; 1 \gg)$, where T_1 and T_2 are types of individuals.

The meaning constraint for a determiner $\mathcal{F}(\delta)$ is:

(3.2) For a given parameter assignment c defined by a particular context of use, the proposition (3.1) is true iff:

    (a) $c(s) \models \ll \mathcal{F}(\delta), QDomain : c(T_1), QRange : c(T_2); 1 \gg$, and

    (b) if the situation $c(s)$ is *informative*, then the specified by $\mathcal{F}(\delta)$ quantity of objects of type $c(T_1)$ are also of type $c(T_2)$.

The primitive quantitative relation $\mathcal{F}(\delta)$ and the meaning constraint associated with a determiner δ have to be given by the lexicon of the situational grammar. The particular quantity denoted by some of the determiners, such as *most*, is highly context dependent. For such determiners, the constraints will be underspecified to one or other extend. The grammar rules have to give the compositional power of the primitive relation $\mathcal{F}(\delta)$, which is:

(4) $\lambda T_1 [T_2/(s \models \ll \mathcal{F}(\delta), T_1, T_2; 1 \gg)]$, where T_1 and T_2 are parameters for types of individuals.

The grammar rules[4] should assign, in a compositional way, the following basic type meaning of a noun phrase $[[\delta]_{Det}[\alpha]_N]_{NP}$:

(5) $[T_2/(s \models \ll \mathcal{F}(\delta), [x/\dot{p}(x, s_j, l_j)], T_2; 1 \gg)]$, where the type $[x/p(x, s_j, l_j)]$ is the meaning of the noun α.

For example, the type meaning σ of the noun phrase A STUDENT is:

(6) $\sigma = [T/(s \models \ll a, [x/(s_j \models \ll student, x, l_j; 1 \gg)], T; 1 \gg)]$.

3   Linguistic Meaning and Quantification

The meanings can be parameterized not only in the trivial sense that they have individual parameters as constituents. They can have opened and unresolved semantical structures as in the cases of quantificational scope ambiguity: EVERY STUDENT IS WATCHING A MOVIE. There are two plausible interpretations. *De re* interpretation in which there is a specific movie

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[3] A formalization of this notion is proposed in [Loukanova and Cooper 1999].

[4] See [7], [14].

and all students in the described situation are watching it. In *de dicto* interpretation every student is watching their own movie. In absence of enough contextual information, the scope alternatives are open. Which one would be the case would be up to the speaker's references. Here I shall follow a semantical approach toward scope resolving as dependent on the context. For a similar situational approach and more argumentation, see [Gawron and Peters, 1990]. The present situational framework though uses a semantical storage to represent all unresolved quantificational options. For simplifying the representation, in what follows, I shall index the NPs. The indices are pairwise different when the NPs are not anaphoric, while the anaphoric NPs have to be co-indexed, as in JOHN$_1$ MET A PHILOSOPHER WHO LIKED HIM$_1$. In situation semantics considered in the present paper, the linguistic meaning $[\![\alpha]\!]$ of an expression α is defined to be a pair of two semantical objects: $[\![\alpha]\!] = \langle \mathcal{M}(\alpha), \mathcal{B}(\alpha) \rangle$, where $\mathcal{M}(\alpha)$ is called quantificational *storage* of α, and $\mathcal{B}(\alpha)$ — *basis*[5] of α. The storage $\mathcal{M}(\alpha)$ collects the semantical representations of quantificational noun phrases occurring in α. For example, in case that the quantificational binding has not yet taken place, the storage and the basis of the simple quantificational sentence $\alpha =$ EVERY STUDENT WALKS are:

$\mathcal{M}(\alpha) = \{\langle \sigma, x_1 \rangle\}$, where
$\sigma = [T/(s_{q_1} \models \ll every, [x/(s_1 \models \ll student, x, l_1; 1 \gg)], T; 1 \gg)]$, and
$\mathcal{B}(\alpha) = (s \models \ll walk, x_1, l; 1 \gg)$.

The type σ is the situational meaning of the NP EVERY STUDENT, i.e. an abstraction over *QRange* of the determiner relation *every*, where the *QDomain* role has been filled up by the type meaning of the noun. Thus the storage contains the pair $\langle \sigma, x_1 \rangle$ which consists of the semantical representation of the quantified NP and a parametric representative x_1 of *QRange* of *every*. The basis, $\mathcal{B}(\alpha)$, is the propositional content of the *QRange*. It represents "the skeleton" of the semantical structure of the sentence, i.e. its basic predication applied to one of the indeterminate representatives of the quantifier. The sentence α contains only one quantified NP and there is only one possibility for getting a particular interpretation with respect to quantificational scope: the type σ has to be applied to the type $[x_1/(s \models \ll walk, x_1, l; 1 \gg)]$ obtained by abstraction over the parameter x_1 in $\mathcal{B}(\alpha)$. The new storage and the new basis of α are:

$\mathcal{M}'(\alpha) = \emptyset$,
$\mathcal{B}'(\alpha) = (s_{q_1} \models \ll every, [x/(s_1 \models \ll student, x, l_j; 1 \gg)],$
$\qquad\qquad [x_1/(s \models \ll walk, x_1, l; 1 \gg)]; 1 \gg)$.

The simplest steps of the quantificational process for a sentence α with a storage $\mathcal{M}(\alpha)$ and a basis $\mathcal{B}(\alpha)$ can be stated in the following way. Let $\langle \sigma, x_i \rangle \in \mathcal{M}(\alpha)$, where:

$\sigma = [T/(s \models \ll \mathcal{F}(\delta), [x/p(x, s_j, l_j)], T; 1 \gg)]$, then:

1. Take the quantificational type pair $\langle \sigma, x_i \rangle$ out of the storage. The result is the new storage:
   $\mathcal{M}'(\alpha) = \mathcal{M}(\alpha) - \{\langle \sigma, x_i \rangle\}$.

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[5]The objects $\mathcal{M}(\alpha)$ and $\mathcal{B}(\alpha)$ can be generated in a compositional way by the rules of a situational grammar as in [14].

2. The new basis is: $\mathcal{B}'(\alpha) = (\sigma : [x_i/\mathcal{B}(\alpha)])$. After the relevant substitutions, the result is filling up the $QRange$ role of $\mathcal{F}(\delta)$ with the type $[x_i/\mathcal{B}(\alpha)]$, and the new basis is:

$$\mathcal{B}'(\alpha) = (s \models \ll \mathcal{F}(\alpha), [x/p(x, s_j, l_j)], [x_i/\mathcal{B}(\alpha)]; 1 \gg).$$

Let us consider a sentence with two quantified NPs:
$\gamma = [\text{EVERY LOGICIAN}]_1$ MET $[\text{A PHILOSOPHER}]_2$.
Out of any context, the storage and the basis are:
$\mathcal{M}(\gamma) = \{\langle \sigma_1, x_1 \rangle, \langle \sigma_2, x_2 \rangle\}$, where
$\sigma_1 = [T/(s_{q_1} \models \ll every, [x/(s_1 \models \ll logician, x, l_1; 1 \gg)], T; 1 \gg)]$,
$\sigma_2 = [T/(s_{q_2} \models \ll a, [x/(s_2 \models \ll philosopher, x, l_2; 1 \gg)], T; 1 \gg)]$, and
$\mathcal{B}(\gamma) = (s_d \models \ll meet, x_1, x_2; l_d \gg)$.

There are two different possible ways to get the storage emptied and, by this, the quantificational ambiguity solved in one or other way:

Case1: $\mathcal{B}'(\gamma) = (\sigma_2 : [x_2/(\sigma_1 : [x_1/\mathcal{B}(\gamma)])])$

First, the quantificational type σ_1 is applied to the individual type $[x_1/\mathcal{B}(\gamma)]$. The basis $\mathcal{B}(\gamma)$ becomes the predicate content of the type that fills $QRange$ role of $every$. Then the quantificational type σ_2 is applied to the abstraction over x_2 in the latter obtained predication. By this the predicate content of the $QRange$ of a gets filled up, and the final result is:

$\mathcal{B}'(\gamma) =$
$(\sigma_2 : [x_2/(s_{q_1} \models \ll every, [x/(s_1 \models \ll logician, x, l_1; 1 \gg)]$,
$\qquad\qquad\qquad [x_1/(s_d \models \ll meet, x_1, x_2, l_d; 1 \gg)]; 1 \gg)]) =$

$(s_{q_2} \models \ll a, [x/(s_2 \models \ll philosopher, x, l_2; 1 \gg)]$,
$\qquad\qquad [x_2/(s_{q_1} \models \ll every, [x/(s_1 \models \ll logician, x, l_1; 1 \gg)]$,
$\qquad\qquad\qquad\qquad [x_1/(s_d \models \ll meet, x_1, x_2, l_d; 1 \gg)]; 1 \gg)];$
$\qquad\qquad\qquad\qquad 1 \gg).$

Case2: $\mathcal{B}'(\gamma) = (\sigma_1 : [x_1/(\sigma_2 : [x_2/\mathcal{B}(\gamma)])]) =$

$(s_{q_1} \models \ll every, [x/(s_1 \models \ll logician, x, l_1; 1 \gg)]$,
$\qquad\qquad [x_1/(s_{q_2} \models \ll a, [x/(s_2 \models \ll philosopher, x, l_2; 1 \gg)]$,
$\qquad\qquad\qquad\qquad [x_2/(s_d \models \ll meet, x_1, x_2, l_d; 1 \gg)]; 1 \gg)];$
$\qquad\qquad\qquad\qquad 1 \gg).$

For each quantified NP β_i occurring in α, $\mathcal{M}(\alpha)$ may contain a pair $\langle \sigma, x_i \rangle$, where σ is the meaning of β_i, i.e. σ is a type such as in (5) and (6). The basis $\mathcal{B}(\alpha)$ is the propositional content of the eventual filler of the $QRange$ role of the quantificational relation $\mathcal{F}(\delta)$ in σ. The parameter x_i is a constituent of $\mathcal{B}(\alpha)$, interpreted as a fixed indeterminate representative of the selected quantity of individuals from the domain, which are also in the range. An abstraction over x_i in $\mathcal{B}(\alpha)$ will give the type that will fill up the $QRange$ role of $\mathcal{F}(\delta)$. By this, the basis, $\mathcal{B}(\alpha)$,

represents the predicative structure of α, where some of the argument roles of the constituent relations are filled up by parameters x_i. If $\langle \sigma, x_i \rangle \in \mathcal{M}(\alpha)$, then at a later stage of analysis of a larger expression, or in getting a particular scope interpretation in a context of use, the type σ will be quantified into the basis, and by this will bind the parameter x_i occurring in it. When there is not enough information for resolving some quantificational ambiguity, σ may be left in storage. Generally, the storage $\mathcal{M}(\alpha)$ of an expression α is a set: $\mathcal{M}(\alpha) = \{\langle \sigma_1, x_{i_1} \rangle, \dots, \langle \sigma_k, x_{i_k} \rangle\}$, where $k \geq 0$, and $i_1, \dots, i_k$ are pairwise different natural numbers that are indices of NPs occurring in α; $\sigma_1, \dots, \sigma_k$ are the type meanings of the corresponding NPs. Formally, each number i_j, $j = 1, \dots, k$ is the index of the argument role $[x_{i_j}]$ of the type that has to fill up the *QRange* role of the quantitative relation in σ_j. The quantificational process permits more than one "insertion" at a time. Let α be a sentence with a linguistic meaning $[\![\alpha]\!] = \langle \mathcal{M}(\alpha), \mathcal{B}(\alpha) \rangle$, such that $\{\langle \sigma_1, x_{i_1} \rangle, \dots, \langle \sigma_k, x_{i_k} \rangle, \} \subseteq \mathcal{M}(\alpha)$, where $k \geq 0$ and the indices $i_1, \dots, i_k$ are pairwise different. Then

Quantification Rule

1. $\mathcal{M}'(\alpha) = \mathcal{M}(\alpha) - \{\langle \sigma_1, x_{i_1} \rangle, \dots, \langle \sigma_k, x_{i_k} \rangle\}$, and
2. $\mathcal{B}'(\alpha) = (\sigma_1 : [x_{i_1} / \dots (\sigma_k : [x_{i_k} / \mathcal{B}(\alpha)]) \dots])$.

Which of the quantifiers are taken out of the storage and moved into the basis, and the order of the quantification is dependent on the linguistic and contextual information available. The order of the quantification, though, must respect the following restriction which prevents leaving relevant parameters to occur freely without being abstracted over:

Quantificational Restriction

(i) In the quantifier order: $\langle \sigma_1, x_{i_1} \rangle, \dots, \langle \sigma_k, x_{i_k} \rangle$, there must be no $m, n \in \{1, \dots, k\}$ such that $m \leq n$ and x_{i_n} is a free parameter in σ_m;

(ii) $x_{i_1}, \dots, x_{i_k}$ are not free parameters of the type meanings left in the new storage $\mathcal{M}'(\alpha)$.

When the linguistic meaning of an expression α is such that $\mathcal{M}(\alpha) \neq \emptyset$, the pair $[\![\alpha]\!] = \langle \mathcal{M}(\alpha), \mathcal{B}(\alpha) \rangle$ can be subject to further semantical computations. When the storage $\mathcal{M}(\alpha)$ contains more than one quantifier, this could be because there is not enough linguistic or extra-linguistic information for resolving the available ambiguity caused by the occurrence of more than one NP in α. In this way the domains and the ranges of the quantifications involved are generally context dependent on the speakers references. There are also cases when the quantificational order is governed by linguistic restrictions and generalizations as it is pointed in [10].

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