Nominal Scope in Situation Semantics

Roussanka Loukanova

This paper introduces a semantical storage approach for representation of the nominal quantification in situation semantics. The 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 quantifiers are in the storage. A generalized quantificational rule moves some of the quantifiers out of the storage into the basis. It is a subject of structural restrictions that do not permit free parameters to fall 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 the scope ambiguities.

1 INTRODUCTION

An adequate semantical theory has to account for the *semantical efficiency of the natural languages*, i.e. the possibility for different interpretations of the same language expressions in different contexts of use. The semantics of the natural languages has two sides: abstract, "pure" linguistic meanings in abstraction of any context, and one or other particular interpretation depending on the context of use. A lots of different factors contribute to the complex relations between the "pure" linguistic meanings of the sentences and their interpretations: the circumstances of the context, the speakers' believes, knowledge and intentions. Although the complexity of these relations, there are regularities and uniform constraints that govern the processes of extraction of linguistic meanings and corresponding interpretations out of the linguistic forms. The linguistic meanings themselves consist of structured and parameterized objects open and pending for anchoring to particular, real or abstract, objects. Then, there are also regularities that govern anchoring of the abstract parametric linguistic meanings to particular interpretations. The task of an adequate semantical theory is to represent both kinds of regularities. Hence, a comprehensive and integrated linguistic theory has to account for at least the following stages:

- Linguistic meanings of the phrases in correlation with their syntax;
- Semantical interpretation of the phrases in different circumstances of use.

The syntactic compositionality of the natural languages is compound in sense that the syntactic structures of some constituents depend not only on the syntactic structures of the components, but also on semantical information brought into by them. A grammar theory representing the interdependency between syntax and semantics needs a semantical component of appropriate kind. One of the most challenging candidates for such semantics is situation theory. Situation theory types are structured objects that can reflect the syntactic structures of the language expressions, and in addition are enough finely grained to represent silent semantical and context dependent information. The complex types are the devise for generating structured semantical objects whose components obey various constraints. A basic feature of the objects in the system is that they can be parametric, and by this they are appropriate for representing linguistic meanings in abstraction of any context, or when the context does not supply enough information for anchoring the parameters to specific objects. One and the same system of semantical objects is used for representing both, the parametric linguistic meanings and the interpretations.

The context (and other relevant relevant sources of information) provide appropriate assignment of the parameters occurring in the linguistic meanings and can resolve the available ambiguity. A substantial part of the relation between the natural language expressions and their interpretations can be given in a systematic way by means of context dependent functions assigning appropriate values to the parameters occurring in the corresponding linguistic meanings. These functions could be partial and leaving some of the parameters, or even some lexical and non-lexical ambiguities unresolved as it is in many discourses. Often the listener, or the reader gets parameterized information from what they hear or read. Sometimes, a speaker may use the language namely for expressing partial and parameterized information.

Introductions into Situation Theory are given by [Barwise and Perry 1983; Barwise 1987; Devlin 1991; Fenstad at. all 1987]. A complete guide on the existing literature on situation theory and related topics is given by [Seligman and Moss 1997. An introduction into Montague intensional logic (IL) and PTQ is [Dowty and Peters 1981]. 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 (which might be called a Montagovian style in situation semantics) that copes with quantification scope problems as well as with embedded beliefs, see [Cooper and Ginzburg 1996]. For a detailed discussion of the linguistic arguments and background of an approach toward quantificational scope very close to the one presented in this paper, see [Farkas 1996, 1997a,1997b, 1997c]. It can be very well formalized by semantical storage in situation semantics as proposed here. Next section is a brief informal introduction of some of the situation theoretical objects needed for representing the method of the semantical storage in situation semantics.

2 SOME SITUATION THEORETICAL NOTIONS AND NOTATIONS

Situation theory accepts several kinds of primitive objects, among them: primitive individuals, $\{a, b, c, \ldots\}$; primitive parametric objects, called also indeteterminates, $\{x, y, z, \ldots\}$; space-time locations $\{l, l_0, l_1, \ldots\}$, and primitive relations $\{r, r_0, r_1, \ldots\}$. For example, the nouns and the verbs typically denote primitive properties and relations, such as *student*, *book*, *run*, *walk*, *read*, $\ldots$. Each relation is associated with a set of argument roles and corresponding conditions for their appropriate filling[1]. For example, *read* is a primitive relation with three argument roles: *Subj*, for the subject; *Obj*, for the object; and *Loc*, for the space-time location. The argument structure of the relations (i.e. the set of their argument roles and the corresponding appropriatness conditions) is presented by situational objects called *infons*. Each infon specifies a unique relation, an assignment of its argument roles and a corresponding negative or positive polarity. In this paper, I shall adopt the traditional linear notation of the infons. For example:

(1.1) $\ll read, Subj :a, Obj :b, Loc :l; 1 \gg$,

(1.2) $\ll read, Subj :a, Obj :b, Loc :l; 0 \gg$,

The latter are, respectively, the positive and negative informational pieces which represent that the individual a is reading/not reading an object b in a location l. Complex properties and relations are result of combining infons by boolean connectives and λ-abstraction over some of the parameters:

(2.1) $$\lambda x, y\, (\ll watch, Subj :x, Obj :y, Loc :l; 1 \gg \wedge \ll movie, Subj :y, Loc :l; 1 \gg)$$

[1] The restricted parameters are an appropriate tool for imposing appropriateness conditions over argument role fillings.

(2.2) $\lambda x\,(\ll watch, Subj:x, Obj:b, Loc:l; 1 \gg \wedge$
$\ll movie, Subj:b, Loc:l; 1 \gg)$

(2.3) $\lambda x\,(\ll student, Subj:x, Loc:l; 1 \gg \wedge$
$\ll movie, Subj:y, Loc:l; 1 \gg \wedge$
$\ll watch, Subj:x, Obj:y, Loc:l; 1 \gg).$

The abstraction in (2.1) represents the relation between two objects, one of them watching the other in a particular location l, and the watched one being a movie. This complex relation has two argument roles, denoted by $[x]$ and $[y]$, respectively. The property of watching the particular movie b in the location l is expressed by (2.2) and has only one argument role $[x]$. The property (2.3) of being a student watching a particular, but indeterminate movie y also has only one argument role $[x]$. Here y is a parameter representing an unknown object filling the *Subj* role of the relation *movie*. The propositions that a is walking at l, in a situation s, and that a is reading the book b at l, in a situation s, are represented, correspondingly, by:

(3.1) $(s \models \ll walk, Subj:a, Loc:l; 1 \gg),$

(3.2) $(s \models \ll read, Subj:x, Obj:b, Loc:l; 1 \gg \wedge$
$\ll book, Subj:b, Loc:l; 1 \gg).$

The abstractions over individuals in propositions result in types of individuals $\lambda x_1, \ldots, x_n p(x_1, \ldots, x_n)$ which also have their own argument roles $[x_1], \ldots, [x_n]$. I shall follow a notational tradition in situation semantics by which, in the particular cases of abstraction over propositions, the type resulted is denoted by: $[x_1, \ldots, x_n / p(x_1, \ldots, x_n)]$.

(4.1) $[x/(s \models \ll walk, Subj:x, Loc:l; 1 \gg)],$

(4.2) $[x/(s \models \ll read, Subj:x, Obj:b, Loc:l; 1 \gg \wedge$
$\ll book, Subj:y, Loc:l; 1 \gg)],$

Everywhere in this paper, s is taken to be a parameter, i.e. to represent an indeterminate, probably unknown, or just unspecified situation. In the type (4.2) there is one more parameter y which makes (4.2) represent the type of an object reading a particular, although indeterminate book y in s. In a given context, the user's references may anchor the parameters y and s to one or other specific object and situation, respectively. The effect of the intensional functionality of the types is achieved by using situated propositions and abstractions over situations in types:

(4.3) $\lambda s[x/(s \models \ll walk, Subj : x, Loc : l; 1 \gg)]$,

(4.4) $\lambda s[x/(s \models \ll read, Subj : x, Obj : b, Loc : l; 1 \gg \wedge \ll book, Subj : y, Loc : l; 1 \gg)]$.

Often for simplicity, only the objects filling the argument roles shall be explicitly written in the infons, without specifying the roles themselves. For example, the type (4.2) can be written:

(4.5) $[x/(s \models \ll read, x, y, l; 1 \gg \wedge \ll book, y, l; 1 \gg)]$

Some more notations 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.

In the following sections we will consider a situation semantics for some English expressions. It will be associated with an interpretation function $\mathcal{F}$ defined for the lexical units and giving their semantical counterparts: $\mathcal{F}$(STUDENT)= $student$, $\mathcal{F}$(WALK)= $walk, \ldots$.

3 NOMINAL QUANTIFICATION — SCOPE, DOMAIN AND RANGE

A quantificational sentence like:

(5) EVERY STUDENT WALKS.

is translated into a language of first order logic (f.o.l.) by the formula:

(6) $\forall \mathsf{x}(\mathsf{student}(\mathsf{x}) \rightarrow \mathsf{walk}(\mathsf{x}))$.

The translation of (5) into Montague style intensional logic (IL), like that used in PTQ, is equivalent to the same expression (6). The difference is in the language, and that the translation process from English to Montague IL is compositional. Actually, there are intermediate calculations for getting (6) from the primary translation of (5). The natural language quantification expressed by a simple sentence like (5) may be depicted by the following schemata:

(7)

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

The scheme (7) might be interpreted in the following way. QDomain of the quantification is the set of the objects having the property denoted by the noun of the quantified NP. QRange of the quantification is the set of objects satisfying the property denoted by the VP of the sentence. Then:

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

For the sentence (5) the quantity expressed by the Determiner is all available objects from the QDomain. The suggestion in this work, as well as in [Farkas 1997a, b, c], is that 8(a) is respected by all quantitative determiners like EVERY, A, SOME, FEW, MANY, MOST, ONE, TWO, THREE, ... By this the concept of a quantificational scope covers two separate semantical notions — of a domain and a range of the particular quantification.There are two other ways we can interpret the quantification expressed by a sentence like (5):

8(b) 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 (distributivley or collectively) denoted by the noun.

8(c) 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.

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

To unify the translations of the quantified NPs with those that are simple individual terms, Montague, in PTQ, chosen the interpretation 8(c) and went to the the most significant generalization toward a unified semantical representation of the NPs: a name does not directly denote the individual j having that name, but rather the characteristic function of the set of the properties of that individual, $\lambda \mathsf{P}(\mathsf{P}\{\mathsf{j}\})$. The quantification expressed by (5) and its PTQ translation can be depicted in the following way:

(7.1)

$$\begin{array}{llll}
 & \mathsf{Determiner} & \mathsf{QDomain} & \mathsf{QRange} \\
 & every & [\![\text{STUDENT}]\!] & [\![\text{WALKS}]\!] \\
\text{(ii)} & (\lambda \mathsf{Q} \lambda \mathsf{P} \forall \mathsf{x}(\mathsf{Q}\{\mathsf{x}\} \rightarrow \mathsf{P}\{\mathsf{x}\}) & (\hat{\ } \,\mathsf{student})) & (\hat{\ }\, \mathsf{walk}) \\
\text{(iii)} & \underbrace{\forall x}_{Quantifier} & \multicolumn{2}{l}{\underbrace{(\mathsf{student}(\mathsf{x}) \rightarrow \mathsf{walks}(\mathsf{x}))}_{\mathsf{Scope}}}
\end{array}$$

Here $[\![$STUDENT$]\!]$ and $[\![$WALKS$]\!]$ are the meanings of the words STUDENT and WALKS, respectively, taken for now in some informal intuitive way. Line (i) stands for some intuition about what (5) might mean, for example, $every$ is a two argument quantitative relation between properties, and the properties $[\![$STUDENT$]\!]$ and $[\![$WALKS$]\!]$, are in its QDomain and QRange, respectively. The traditional syntactic notion of a scope in f.o.l., and in IL, is about the scope of the quantifiers $\forall \mathsf{x}$ and $\exists \mathsf{x}$, while the natural languages quantifiers are NPs which are combinations of a determiner and a noun. The variable x is used to represent the binding process and the connecting link between QDomain and QRange. I.e. x denotes the representatives of the QDomain which have to be also in the QRange. The symbol $\forall$ corresponds to the determiner word EVERY, and the quantifier is the expression $\forall \mathsf{x}$, which represents the quantity plus a particular varying representative. The meaning of the expression $\forall \mathsf{x}$ in $\forall \mathsf{x} \mathsf{p}(\mathsf{x})$, though, is unary, while the natural language determiner EVERY has binary-relational meaning. The choice of the implication sign "$\rightarrow$" represents the relational part of the meaning of the determiner EVERY, i.e. the sign "$\rightarrow$" together with the symbol $\forall$ expresses the $quantitative$ relation between QDomain and QRange. Although (6) is a good semantical approximation of (5), there is a syntactical shift about what is the quantifier and what is the scope. In natural language, NPs like $[$EVERY STUDENT$]_{NP}$ are quantifiers, while in (6) $\forall \mathsf{x}$ is turned into the Quantifier and it binds the variable x in the scope $(\mathsf{student}(\mathsf{x}) \rightarrow \mathsf{walks}(\mathsf{x}))$. The syntactical scope structures for simple English sentences like (5), can be easily separated, but for more complex sentences that would not be possible without going through some extra-syntax such as quantifier raising, and quantificational rules as, for example, in type-logic theories. We shall see how the above quantificational scheme (7) can be represented in situation semantics without introducing the additional variable x for turning the determiner EVERY into the quantifier $\forall x$. Rather, the appropriate connection between QDomain and QRange shall be governed at the semantical level by appropriate types of individuals (see [Barwise and Cooper 1986; Barwise 1986]).

4 QUANTIFICATIONAL STRUCTURES IN SITUATION SEMANTICS

In situation semantics, the determiners can be considered as denoting primitive relations between types of individuals, see [Cooper 1993; Cooper and Ginsburg 1996]. For example, let *every, a, some, most, one, two, ...* be the primitive relations considered as the semantical counterparts of the lexical quantitative determiners EVERY, A, SOME, MOST, ONE, TWO, ..., respectively. Each of the quantificational relations δ 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 (5) is expressed by the proposition:

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

The situation s is the *described situation* which supports the quantificational information. The situation s_j is where walking takes place, and it could be the same as s. The situation s_i is the one in which the noun $[\text{STUDENT}]_N$ is evaluated. It is called the *resource situation* of the NP $[\text{EVERY STUDENT}]_{NP}$. It might be that some of these three situations are the same, but they could be also different. The above proposition is true just in case that every individual who is a student in the situation s_i is also an walker in the situation s_j. The quantificational scheme (7) for sentences like (5) can be depicted in the following way:

(7.2)

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 (7.1) and (7.2) 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 (7.1) are syntactical representatives of the corresponding natural language sentence into IL, aiming to represent the corresponding semantics of the quantification. Line (i) in (7.1) represents an intuition about the semantics of a corresponding relational treatment of the determiner EVERY. In contrast to (7.1) (ii)-(iii), (7.2) is a semantical representation.

One notorious semantical problem concerns the attitude verbs. Many of those problems are solved by introducing the intensional operator ˆ and respectively possible worlds indices. The totality of the possible worlds though, in its turn, brings into semantical inadequacy, too. For detailed discussion see [Barwise1987]. Originally, situation theory emerged as a theory representing the partiality of the information and information flow phenomena, and in particular, of the linguistic semantic information — the speakers use natural language to transfer partial information about partial situations, i.e. about "small possible worlds" in contrast to total possible worlds. In such sense, the total possible worlds are introducing "too much" into the semantical descriptions. But in another sense, the IL worlds cannot present as constituents of the internal structure of the semantical objects. For example, the intensional operator ˆ in (ii) of (7.1) gets absorbed during the intermediate calculations, and the final representation by (iii) can have the possible world (and location) only at the outer level via the notion of the intension of the entire expression. There are strong intuitions about the meanings ⟦WALKS⟧ and ⟦STUDENT⟧ should carry implicit information about situations where walking and being a student take place, and these two situations might be different. Both of (ii) and (iii) lack to represents this important semantical information expressed by an utterance of the sentence (5). While the situational $\mathsf{QDomain}$ and QRange types in (7.2) 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 (7.1) and (7.2) is that there is no additional quantifier $\forall \mathsf{x}$ in (7.2). The relevant binding is achieved by the argument roles of $\mathsf{QDomain}$ and QRange types. The quantifier $\forall \mathsf{x}$, 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.

Even if there were no expressions involving quantificational scope ambiguities, the situational 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 (7.1), 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 by using some additionally complicated syntax:

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

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

As shown in the following part of the article, disambiguating can be done at the level of the semantical evaluation. The syntactical structures in the natural languages, even with added quantificational extra-syntactical rules, are less fine grained than the corresponding semantical structures and processes.

The quantitative meaning of a determiner like EVERY, A, SOME, ONE, TWO, ... have two sides — invariant and varying, that are not in one-to-one correspondence to the surface syntax of the quantitative expressions.

(i) The invariant side of the lexical meanings of the quantitative determiners is that they denote two argument primitive quantificational relations between types of individuals.

(ii) The varying part of the lexical meaning of a quantitative determiner is the particular 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 — *all, one, at least one, no, two,* and so on, 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 also [Barwise and Perry 1983]. For a simple sentence with only one quantitative NP which is the subject of the sentence, the 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.

In what follows we shall need one more notion from situation theory, that of a *restricted parameter*. An individual type r can be used to put a restriction over a parameter x, the resulted object is denoted by x^r. The restricted parameters have a presuppositional effect: the proposition $\Theta(x^r)$ is a legal object iff the object $c(x)$ is of type r.

Linguistic Meaning and Interpretation

The natural language expressions are, in their larger part, ambiguous when considered out of any context. Still they are meaningful and that is why we are able to use them for communications. They are meaningful in sense that their linguistic meanings are parametric semantical objects that carry partial semantical information. The sentence "JON IS WALKING" taken out of any context is meaningful in sense that it can be used for describing a situation in which an individual is walking. In addition, a speaker would use this sentence if she knew (or believed) that the walker was named Jon. In a particular context of uttering this sentence, the speaker would refer to a particular individual j by the name JON, and would describe a particular situation s_0 in which that individual j had the property of walking, i.e. the propositional content of the interpretation of the sentence would be: $(s_0 \models \ll walk, j, l_0; 1 \gg)$. The propositional content of the linguistic meaning out of any context is the parametric proposition

$(s \models \ll walk, x^{[x|(u \models \ll named, \mathrm{JON}, x; l_u \gg)]}, l; 1 \gg)$, where

s, x, u, l_u are all parameters for a described situation, an individual referred to, naming circumstances and a location of those circumstances, respectively. In the absence of enough relevant linguistic or contextual information, even the interpretations can be parametric. For example, the speaker might be uttering the above sentence without knowing who was the individual j, and without any perceptual referring to him. In such case, the interpretation might be:

$(s_0 \models \ll walk, x^{[x|(u \models \ll named, \mathrm{JON}, x; l_u \gg)]}, l_0; 1 \gg)$.

Situation theory provides tools for a two-fold semantical representation of a given expression α: its linguistic meaning in abstraction from the particular cases of use which shall be denoted by $[\![\alpha]\!]$; and one or other interpretation in a given context. Various contextual elements, including the speakers references provide anchoring the parameters of the linguistic meaning to particular objects. I.e. in a particular context, or circumstances of using an expression α, speaker's references supply with an *assignment function* c defined over the parameters of $[\![\alpha]\!]$. Substituting the speaker's referents, $c(x)$ for every parameter x occurring in the linguistic meaning $[\![\alpha]\!]$ is yielding the interpretation of α in the given context. In what follows I shall use the following notation: whenever Θ is a situational object, for example such that represents the linguistic meaning of α, $c(\Theta)$ is the result of the application of the substitution defined by the assignment c over Θ. For a formal definition of the situational notions of assignment and substitution, see for example, [Barwise and Perry 1983], or [Loukanova and Cooper 1999].

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 of 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:

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

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

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

be really in the specified quantificational relation. For example, $c(s_q)$ might be a visual (or believe) situation which does not represent all actual states of affairs, or wrong such. Generally, the propositional content of a quantification defined by a determiner δ is:

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

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

(14.2) For a given parameter assignment c defined by a particular context of use, the proposition (14.1) 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 $\mathcal{F}(\delta)$ corresponding to a determiner δ has to be given by the lexicon of the situational grammar. The grammar rules also have to give the semantical structure of this primitive relation, which is:

(15) $\lambda T_1 \, [T_2/(s \models \ll \mathcal{F}(\delta), T_1, T_2; 1 \gg)]$, 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 $[[\delta]_{Det}[\alpha]_N]_{NP}$:

(16) $[T_2/(s \models \ll \mathcal{F}(\delta), [x/p(x, s_j, l_j)], T_2; 1 \gg)]$, 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:

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

The particular quantity denoted by some of the determiners, such as *most* is highly context dependent.

5 LINGUISTICS 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

[4] see [Cooper and Ginsburg 1996; Loukanova 1991; Loukanova 1999]

STUDENT IS WATCHING A MOVIE. There are two plausible interpretations. The *de re* interpretation in which there is a specific movie and all students in the described situation are watching it. In the *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. Also no syntactical representations[5] of the expressions are considered. The only presumption is that an eventual syntax component should not have any quantificational extra-syntactical rules generating scope disambiguated syntactical structures.

For simplifying the representation in what follows, I shall index all NPs occurring in one or other expression. The indices are pairwise different when the NPs are not anaphoric, while the anaphoric NPs have to be co-indexed, as in JON$_1$ MET A PHILOSOPHER WHO LIKES 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 the quantificational *storage* of α, and $\mathcal{B}(\alpha)$ — the *basis*[6] of α. The storage $\mathcal{M}(\alpha)$ collects the semantical representations of quantified 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 α = 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 the QRange of the determiner relation *every*, where the $\mathsf{QDomain}$ 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 the 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, in which the quantifier is

[5]In HPSG the semantical contents of the expressions correspond to their situational representations.

[6]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 [Loukanova 1991 and Loukanova 1999].

represented by one of its indeterminate representatives. 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:

$\mathcal{M}'(\alpha) = \emptyset$,

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

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:

   $\mathcal{M}'(\alpha) = \mathcal{M}(\alpha) - \{\langle \sigma, x_i \rangle\}$.

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:

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

As the example above shows, taking a quantificational type meaning out of the storage and inserting it into the basis is technically ”inserting the basis into the quantifier“, i.e. the new type obtained by abstraction over x_i in the basis fills up the $QRange$ argument role of the determiner. The other terminology, ”taking a quantificational type meaning out of the storage and moving it into the basis“ is more consistent with the act of moving the quantifier from the old storage into the new basis after filling the $QRange$ argument role. Let us consider a sentence with two quantified NPs:

γ = [EVERY LOGICIAN]$_1$ MET [A PHILOSOPHER]$_2$.

Out of any context, the storage and the basis are:

$\mathcal{M}(\gamma) = \{\langle \sigma_1, x_1 \rangle, \langle \sigma_2, x_2 \rangle\}$, whereg

$\sigma_1 = [T/(s_{q_1} \models\ll every, [x/(s_1 \models\ll logician, x, l_1; 1 \gg)], T; 1 \gg)]$,

$\sigma_2 = [T/(s_{q_2} \models\ll a, [x/(s_2 \models\ll philosopher, x, l_2; 1 \gg)], T; 1 \gg)]$, 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:

$\mathcal{B}'(\gamma) =$

$$
\begin{aligned}
&(\sigma_2 : [x_2/(s_{q_1} \models \ll every, [x/(s_1 \models \ll logician, x, l_1; 1 \gg)], \\
&\qquad\qquad [x_1/(s_d \models \ll meet, x_1, x_2, l_d; 1 \gg)]; 1 \gg)]) =
\end{aligned}
$$

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

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

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

Generally, 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 (16) and (17). 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 set, which are also in the range set. 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 over/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 pending in the storage for more information. Generally, the storage $\mathcal{M}(\alpha)$ of an expression α is a set: $\mathcal{M}(\alpha) = \{\langle\sigma_1, x_{i_1}\rangle, \ldots, \langle\sigma_k, x_{i_k}\rangle\}$, where $k \geq 0$, and $i_1, \ldots, i_k$ are pairwise different natural numbers (i.e. $x_{i_1}, \ldots, x_{i_k}$ are different parameters) that are indices of NPs occurring in α; $\sigma_1, \ldots, \sigma_k$ are the type meanings of the corresponding NPs. Formally, each number i_j, $j = 1, \ldots, k$ 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 general 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 $\{\langle\sigma_1, x_{i_1}\rangle, \ldots, \langle\sigma_k, x_{i_k}\rangle,\} \subseteq \mathcal{M}(\alpha)$, where $k \geq 0$ and the indices $i_1, \ldots, i_k$ are pairwise different. Then

Quantification Rule

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

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: $\langle\sigma_1, x_{i_1}\rangle, \ldots, \langle\sigma_k, x_{i_k}\rangle$, there must be no $m, n \in \{1, \ldots, k\}$ such that $m \leq n$ and x_{i_n} is a free parameter in σ_m;

(ii) $x_{i_1}, \ldots, x_{i_k}$ 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 $[\![\alpha]\!] = \langle\mathcal{M}(\alpha), \mathcal{B}(\alpha)\rangle$ has to be subject to further semantical computations. That might be because α is a constituent of a larger expression, the generation of which has not yet been completed, and not all of the ranges of the quantifiers have been completely introduced. 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.

6 CONCLUSION

Situational type theory can be used for representing two semantical stages.

1. *"Pure" linguistic meanings* of the natural language expressions. The semantical structure of the linguistic meaning of an expression reflects its compound syntactic category and have parameters pending to be contextually evaluated.

2. The particular *interpretations* of the expressions in one or other context of use are result of combining of the parametric linguistic meaning with appropriate context information. The relevant context elements operate not only as anchoring functions over parameters (represented by functional application and λ-conversion), but also as ambiguity resolving semantical operators. The "pure" linguistic meanings are those structures that has to be tightly and interdependently connected with the syntactical structures. While the interpretations are dependent on information which is not directly expressed by the syntactic forms. The interpretation of a particular use (i.e. utterance) of an expression α from the perspective of the speaker is obtained from the linguistic meaning by:

   - assigning appropriate values, which might be again parametric objects, to the free parameters occurring in $[\![\alpha]\!]$ by speaker's references (often called speaker's connections) and applying to $[\![\alpha]\!]$ the induced substitution in the linguistic meaning;
   - applying the quantificational rule and by this moving the quantifiers from the storage $\mathcal{M}(\alpha)$ into the basis in an appropriate order depending on the available linguistic and extra-linguistic information.

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 [Farkas 1997a].

REFERENCES

Barwise, Jon and Robin Cooper. 1981. *Generalized Quantifiers and Natural Language.* Linguistics and Philosophy 4 (1981):159-219.

Barwise, Jon and John Perry. 1983. *Situations and Attitudes.* Cambridge, MA:MIT press.

Barwise, Jon. 1986. *Noun Phrases, Generalized Quantifiers and Anaphora.* Generalized Quantifiers, ed. P. Gardenfors. Studies in Language and Philosophy. Dordrecht: Reidel Publishing Company.

Barwise, Jon. 1987. *The situation in Logic.* CSLI Lecture Notes Number 17. Stanford: CSLI Publications.

Cooper, Robin and Jon Barwise. 1991. *Extended Kamp Notation: A Grafical Notation for Situation Theory.* in Aczel, Peter, David Israel, Yasuhoro Katagiri, and Stanley Peters, eds. *Situation Theory and Its Applications. Volume 3.* CSLI Lecture Notes Number 37. Stanford: CSLI Publications.

Cooper, Robin. 1983. *Quantification and Syntactic Theory.* Dordrecht, Reidel.

Cooper, Robin. 1993. *Generalized Quantifiers and Resource Situations.* in Aczel, Peter, David Israel, Yasuhoro Katagiri, and Stanley Peters, eds. *Situation Theory and Its Applications. Volume 3.* CSLI Lecture Notes Number 37. Stanford: CSLI Publications.

Cooper, Robin and Jonathan Ginsburg. 1996. *A Compositional Situation Semantics for Attitude Reports.* in Seligman, Jerry, and Dag Westerstahl, eds. *Logic, Language and Computation. Volume 1.* CSLI Lecture Notes Number 58. Stanford: CSLI Publications.

Devlin, Keith. 1991. *Logic and Information.* Cambridge University Press, Cambridge, UK.

Dowty, David, Robert Wall and Stanley Peters. 1981. *Introduction to Montague Semantics.* Studies in Linguistics and Philosophy. Volume 11. Kluwer Academic Publishers. Dordrecht/Boston/London.

Fenstad, Jens Erik, Per-Kristian Halvorsen, Tore Langholm, and Johan van Benthem. 1987. *Situations, Language, and Logic.* Dordrecht: Reidel.

Farkas, Donka. 1996. *Scope Matters.* Proceedings of the workshop on Reference and Anaphorical Relations. Konstanz.

Farkas, Donka. 1997a. *Evaluation Indices and Scope.* in Szabolcsi, Anna, eds. *Ways of Scope Taking.* Studies in Linguistics and Philosophy. Volume 65. Kluwer Academic Publishers. Dordrecht/Boston/London.

Farkas, Donka. 1997b. *Dependent indefinites and scope.* ms., Santa Cruz.

Farkas, Donka. 1997c. *Towards a semantic typology of noun phrases.* ms., Santa Cruz.

Gawron, Jean Mark and Stanley Peters. 1990. *Anaphora and Quantification in Situation Semantics.* CSLI Lecture Notes Number 19. Stanford: CSLI Publications.

Loukanova, R. 1991. *Situation Semantical Analyses of the Natural Language.* Ph.D. dissertation. Moscow State University and Saratov State University.

Loukanova, R. and Robin Cooper. 1999. *Some Situation Theoretical Notions.* Annuaire de l'Universite de Sofia "St. Kliment Ohridski", Faculte de mathematiques et informatique, tome 87(1993), livre 1 - mathematiques, 297–306.

Loukanova, R. 1999. *Semantical Storage: a sample situational grammar.* Indiana University. draft

Muskens, R. 1995. it Meaning and Partiality. Studies in Logic, Language and Information. Stanford: CSLI Publications.

Seligman, Jerry and Lawrence S. Moss. 1997. *Situation Theory.* in Van Benthem, J. and A. ter Meulen, eds. *Handbook of Logic and Language.* Cambridge, MA: MIT Press.

Roussanka Loukanova is an Assistant Professor at the Department of Math. Logic and Applications, Faculty of Mathematics and Computer Science, Sofia University, 1126 Sofia, Bulgaria. Currently she is a visitor at: ILASLL - University of Minnesota, 192 Klaeber Court, 320-16th Avenue S.E., Minneapolis, MN 55455. The work was done at the Department of Computer Science, Indiana University, 215 Lindley Hall, Bloomington, IN 47 405, USA. She can be reached at *e-mail: rloukano@cs.indiana.edu*

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