Quantification and modification represented as feature structures

Harry Bunt
Tilburg University
bunt@uvt.nl

1 Introduction

Quantification in natural language has been studied extensively both by logicians and by formal as well as by computational semanticists. Logical studies of quantification have often focused on the formal properties of quantifier terms as a source of information for valid inference patterns. Computational semanticists have been intrigued especially by the enormous amount of ambiguity that is caused by alternative relative scopings of NPs (e.g. Hobbs and Shieber, 1987). The use of underspecified semantic representations was originally introduced as a way to deal with quantifier scope ambiguities in an efficient manner (Alshawi, 1990; Woods, 1978).

Computational analyses of quantification typically associate with each NP a term consisting of (1) a quantifier; (2) a variable; (3) a restriction; and (4) a body, as illustrated by the following, slightly simplified representation used in Minimal Recursion Semantics (Copestake et al., 1995) for the sentence *Someone sleeps.* The part [*restr*: L_2] represents the restriction of the quantification by means of a pointer L_2 to the representation of *person*, and [*body*: L_3] represents the body with a pointer to the representation of *sleeps.*

$$< \begin{bmatrix} \textit{forsome\_rel} & \\ \textsc{var} & x_1 \\ \textsc{restr} & L_2 \\ \textsc{body} & L_3 \end{bmatrix}, \begin{bmatrix} \textit{person\_rel} & \\ \textsc{handle} & L_2 \\ \textsc{inst} & x_1 \end{bmatrix}, \begin{bmatrix} \textit{sleep\_rel} & \\ \textsc{handle} & L_3 \\ \textsc{eventvar} & x_2 \\ \textsc{agent} & x_1 \end{bmatrix} >$$

In section 2 we will discuss various aspects of quantification that may give rose to ambiguities, besides scope ambiguities. The rest of this paper is organised as follows. In section 3 we will outline an approach to the semantic analysis of quantification in natural language that naturally leads to (possibly underspecified) representations in terms of feature structures. In section 4 we consider some recent developments concerning the definition of feature structures as a standard in natural language processing, including a definition of feature structures as a semantic representation language. In section 5 we will argue that noun modification has many aspects in common with quantification, and that the semantic representation of modification can fruitfully borrow from that of quantification. We end with some concluding remarks in section 6.

2 Aspects of quantification

Quantification may be characterised as the phenomenon that a predicate is applied not to a single argument, but to a set of arguments, or, more generally, that a k-ary predicate is applied to k sets of arguments. In such a case, a number of questions arise concerning the precise way that the predicate is applied to members of these sets.[1] As an example, consider the sentence *Three men moved both pianos.* Some of the questions that may be asked (]it and answered) are the following:

(1) a. Who moved something? (*Some men.*)

b. How many men were involved? (*Three.*)

c. Were these men contextually determined? (*No, they were indefinite.*)

d. What was moved? (*Some pianos.*)

e. How many pianos were involved? (*Two.*)

f. Were these pianos contextually determined? (*Yes, there were two definite pianos.*)

g. Did the men act collectively or individually? (*Don't know. Probably collectively.*)

h. Were the pianos acted upon collectively or individually? (*Don't know. Probably individually.*)

The questions (1a) and (1d) are concerned with the restrictions associated with the two quantifications; (1b) and (1e) are concerned with the numerical specifications associated with the generalised quantifiers *three* and *both*; (1c) and (1f) are concerned with another aspect of quantification, namely the definiteness. Finally, (1g) and (1h) are concerned with yet another aspect of quantification, which we call its *distribution*.

[1] We do not consider mass noun quantification in this paper. See Bunt (1985) for how the notion of a set can be extended to cover non-discrete collections denoted by mass nouns.

In the rest of this section we will consider the distribution aspect of quantification in some more detail, and discuss three more aspects of quantification: the various functions of proportional and numerical indicators associated with quantifiers; the relative scoping of NPs and sets of events relating to verbs; and the phenomenon of equally scoped quantifications.

2.1 Distribution

Besides "ordinary" application of a predicate to the individual elements of a set and the collective application to that set as a whole, another way in which the application of a predicate may be "distributed" over an argument set is groupwise, as in example (2):

(2) This machine picks up 6 bottles and wraps them as a sixpack.

This sentence describes a set of events where a certain machine every time picks up a group of six bottles and packs them.

Given the restriction of a quantification, which specifies a domain from which elements can be taken that participate in events individually, in groups, or collectively, the distribution of a quantification can be seen as a function that allows the computation of the set of those entities that act in the events under consideration as agents, as themes, or in some other role. We call this set the *predication domain*, and the original domain, defined by the restriction, the *reference domain*. In the case of individual distribution, the two domains are the same.

2.2 Functions of proportional and numerical indicators

The most common function of proportional quantifier words like *all, some, most* and numerical or amount quantifiers like *three, more than five, 2 litres* is to specify the absolute or relative part of the reference domain that is involved in the events being considered. Numerical and amount quantifiers may also be used to indicate the size of a reference domain, as in (3):

(3) a. The twelve students in this room all speak two languages.

b. The dog ate all the two and a half kilogrammes of meat.

Another function of these quantifiers is illustrated by (2), where it indicates group size.

Finally, both proportional and absolute quantifier words can be used to indicate the number/amount of a reference domain per element of another predication domain, as in *Each of the dogs ate 5 sausages.*

2.3 NP Scoping relative to events

In a davidsonian approach to sentence meaning, a sentence like (4a) may get a representation like (4b):

(4) a. Everybody will die

b. $\exists e : [\textit{Die-event}(e) \wedge Future(e)] \wedge \forall y : [Person(y) \rightarrow \textit{agent}(e) = y]$

Technically, there is nothing wrong with this representation, but what does it mean? It says that there is a future *die* event of which everybody will be the agent. This is remarkable in two respects; first of all because it allows a *die* event which has billions of individuals in the agent role, which corresponds to a rather peculiar concept of *die* events, and secondly it does not cover the intuitively plausible reading according to which everybody is mortal.

This can be quite a serious problem, since the reified events or situations[2] in a davidsonian representation are sometimes assumed to be existentially quantified with wide scope. For instance, in Minimal Recursion Semantics the sentence (4a) is represented as (5):

(5) $$< \left[\text{TOP\_HANDLE} \quad L_1, \right],$$

$$< \begin{bmatrix} \textit{forsome\_rel} & \\ \text{HANDLE} & L_1 \\ \text{VAR} & x_1 \\ \text{RESTR} & L_2 \\ \text{BODY} & L_4 \end{bmatrix}, \begin{bmatrix} \textit{person\_rel} & \\ \text{HANDLE} & L_2 \\ \text{INST} & x_1 \end{bmatrix}, \begin{bmatrix} \textit{die\_rel} & \\ \text{HANDLE} & L_3 \\ \text{EVENTVAR} & x_2 \\ \text{TIME} & future \\ \text{AGENT} & x_1 \\ \text{THEME} & x_3 \end{bmatrix} >>$$

Free variables in event representations, like x_2 in this example, are tacitly assumed in MRS to have wide scope, so this representation only allows the apocaplytic reading of *Everybody will die.* More generally, the introduction of existentially quantified event variables creates an ambiguity of scoping relative to NP quantifications.

2.4 Quantifications with equal scope

The quantifications of different NPs that act as arguments of a verb, are not always scoped in such a way that one has wider scope than the other. A situation where two quantifications have equal scope is in the 'total-total' or 'cumulative' reading (Partee, 1976; Scha, 1981) of two numerical quantifiers, as in the sentence

(6) Five boys kissed seven girls

[2]In the rest of this paper we will generally speak of "events".

on the reading where the total number of boys that kissed a girl is 5 and the total umber of girls kissed by a boy is 7. Such cases, which cannot be represented adequately with sequences of first-order quantifiers, have also been studied in relation to the use of branching quantifiers (Barwise, 1965).

A slightly different form of equal scoping occurs in what we call *sub-cumulative quantification* (Bunt, 1985), which is illustrated in the following example, occurring in the description of a soccer match that ended in 10–0:

(7) The two Korean players scored 9 goals

The total number of goals scored should not be understood in this case to be 9; the total of 9 goals applies only to the goals scored by the two Korean players.

Computational approaches to quantifier scoping which make us of labels, holes or pointers to allow underspecified scoping and efficient scope disambiguation, have difficulty in dealing with equally-scoped quantifications, as will be immediately clear when considering how the scope labels in the following underspecified MRS representation would have to be instantiated:

(8)
$$< \begin{bmatrix} \text{TOP\_HANDLE} & L_0, \end{bmatrix},$$
$$< \begin{bmatrix} \textit{five\_rel} & \\ \text{HANDLE} & L_1 \\ \text{VAR} & x_1 \\ \text{RESTR} & L_2 \\ \text{BODY} & L_3 \end{bmatrix}, \begin{bmatrix} \textit{boy\_rel} & \\ \text{HANDLE} & L_2 \\ \text{INST} & x_1 \end{bmatrix}, \begin{bmatrix} \textit{kiss\_rel} & \\ \text{HANDLE} & L_4 \\ \text{EVENTVAR} & x_2 \\ \text{AGENT} & x_1 \\ \text{THEME} & x_3 \end{bmatrix},$$
$$\begin{bmatrix} \textit{seven\_rel} & \\ \text{HANDLE} & L_5 \\ \text{VAR} & x_3 \\ \text{RESTR} & L_6 \\ \text{BODY} & L_7 \end{bmatrix}, \begin{bmatrix} \textit{girl\_rel} & \\ \text{HANDLE} & L_6 \\ \text{INST} & x_3 \end{bmatrix} >>$$

3 Quantification as constraints on event-sets

In a davidsonian approach to sentence meaning, we may view the combination of a verb with its arguments as introducing a set of events of the kind indicated by the verb, and with a number of properties concerning the way in which the members of the argument sets are involved in these situations or events. We have now seen the following aspects of quantification that correspond to such properties.

(9)
1. the quantifier's restriction, describing the reference domain of the quantification;

2. the distribution, defining the predication domain;
3. the size of the reference domain;
4. the involvement of the reference domain (in absolute or relative terms);
5. the definiteness of referents from the reference domain;
6. the relative scoping of the quantifications associated with argument NPs;
7. the relative scoping of these quantifications with the existentially quantified events/situations;
8. the size of groups of elements from a reference domain in case of participation in the events/situations of groups of referents;
9. scoped involvement: the number/amount of elements from other reference domains involved in events per element of the predication domain.

If this analysis is correct and complete, then the quantification in a sentence with two NPs, one in subject role and one in direct object role, can be described by the following 18 pieces of information:

(10)

1. the event domain ED;
2. the subject reference domain subj-RD;
3. the subject distribution, defining the predication domain subj-PD;
4. the size of the reference domain subj-RD;
5. the quantity/amount of subj-RD involved in ED-events;
6. the definiteness of the subj-RD;
7. the group size of subj-PD, in case of group involvement
8. the scoping of the subject relative to the set of ED-events;
9. the object reference domain obj-RD;
10. the object distribution, defining the predication domain obj-PD;
11. the size of the reference domain obj-RD;
12. the quantity/amount of obj-RD involved in ED-events;
13. the definiteness of the obj-RD;
14. the group size of obj-PD, in case of group involvement
15. the scoping of the object relative to the set of ED-events;
16. the relative scoping of the subject- and object NPs;
17. the quantity/amount of obj-RD elements involved in events from ED per element of the subj-PD.

18. the quantity/amount of subj-RD elements involved in events from ED per element of the obj-PD.

Mostly, not all these pieces of information are supplied by a sentence, and that is precisely why quantification is such a rich source of ambiguity.

To represent the contribution of quantification to sentence meaning by means of such a list of aspects, a natural suggestion is to use typed feature structures (FSs). For example, an FS representation of a number of the dimensions listed in (10) for the sentence (11) is shown in (12).

(11) The three men moved two pianos.

$$(12)\quad \begin{bmatrix} \textit{move\_events} & \\ \text{EVENTTIMEPERIOD} & \texttt{past}, \\ \text{AGENT-REF-DOMAIN} & \texttt{MEN}, \\ \text{AGENT-DEFINITENESS} & \texttt{def}, \\ \text{AGENT-REFDOM-INVOLVEMENT} & \texttt{3} \\ \text{AGENT-DISTRIBUTION} & \texttt{collective}, \\ \text{THEME-REF-DOMAIN} & \texttt{PIANOS}, \\ \text{THEME-DEFINITENESS} & \texttt{indef} \\ \text{THEME-REFDOM-INVOLVEMENT} & \texttt{2} \\ \text{THEME-DISTRIBUTION} & \texttt{individual}, \end{bmatrix}$$

The use of feature structures for semantic representation is not very popular outside HPSG,[3] and indeed feature structures may be too simple and rigid for full-blown semantic representation. However, FSs may be *embedded* in more powerful representation languages. In the next section we present a formal semantics of FSs in terms of lambda-expressions which makes this point obvious.

4 Feature structure representations

Feature structures can be used to give partial descriptions of any sort of object - usually partial, since not all the values of the features that would be needed for a complete description are available. As such, FSs are a natural candidate for underspecified semantic representation, the more so since FSs already come with structure sharing, as a way to implement the use of labels etc. that has been proposed as a mechanism for the underspecified representation of scope, attachment, etc. (see e.g. Reyle, 1993; Bunt, 2003).

Two related recent developments that may boost the use of FSs in NLP in general and in computational semantics in particular, are, firstly, that the use of XML as an interchange language has rapidly been growing in popularity in language processing systems (see e.g. Kumar and Romary, 2004;

[3]Though in fact Alshawi and van Eijck employ feature structures as constraints in qterm representations of quantification; see Alshawi (1992), ch. 2.

Reithinger, 2001), and secondly that the international standards organisation ISO has recently developed a proposal for a standard implementation of FSs in XML (see Lee et al., 2004; Lee, 2004). The FS language defined in this proposal includes the possibility of features to have set-, list- or multiset values, and negations and disjunctions of values, and as such is potentially quite powerful. In the next subsection we provide a formal semantics of the ISO FS language.

4.1 FS Interpretation by Translation

Feature structures are usually viewed either as a certain type of graphs, i.e. as certain set-theoretical structures, or as representations of graphs (see Bunt & Romary, 2004). In this paper we follow the taken in the ISO definition of feature structures as partial descriptions of objects, i.e., of FSs as denoting sets of properties. We provide a corresponding formal semantics of FSs by specifying a recursive translation of FS translated into λ-expressions, which have a well-established model-theoretic semantics in terms of sets and properties.

We use the following formal language L_1 as the target language of the translation.

lambda-sentence	=::	λx : sentence | λx : lambda-sentence
sentence	=::	$\neg$ sentence | sentence $\veebar$ sentence |
		term_expression = (value_name|s-marker)
term_expression	=::	var | attribute_expression(term_expression)
attribute_expression	=::	attribute_name | predicate_name(term_expression)
attribute_name	=::	$A' \mid B' \mid A'_1 \mid A'_2 \mid ...$
predicate_name	=::	$P \mid Q \mid R \mid ...$
value_name	=::	$v' \mid w' \mid ...$
var	=::	$x \mid y \mid z \mid ....$
s-marker	=::	$z_1 \mid z_2 \mid z_3 \mid ...$

The following set of rules translate any FS into a λ-sentence of L_1. In these rules, Π is a set of paths; $\Pi \backslash \alpha$ is the set of those paths $\pi \in \Pi$ such that the path $\pi.\alpha$ (i.e. π extended with α) belongs to Π. When translating a given FS, Π is initially the set of all paths in the FS. The translation makes use of a set of special variables ('marker variables', akin to discourse markers), and an assignment of such variables to structure sharing markers. We simply indicate this by assigning the variable z_i to the marker $\boxed{\text{i}}$. These variables are understood as implicitly existentially quantified with maximally wide scope. The symbol $\approx$ is used to denote meta-level equality.

1. if τ is the type of a FS, then $T(\Pi, \tau) \approx \lambda x : \tau(x)$
2. if v is an atomic value then $T(\Pi, [A : v]) \approx \lambda x : A'(x) = v'$
3. if fs is a feature structure, i.e. an expression of the form $[Av_1 : v_1, ..., A_n : v_n]$ then $T(\Pi, fs) \approx \lambda x : (T(\Pi, [A_1 : v_1]))(x) \wedge \ldots \wedge (T(\Pi, [A_n : v_n]))(x)$

4. if fs is a feature structure then
$T(\Pi, [A : fs]) = \lambda x : [(\lambda P : P(A'(x))](T(\Pi, fs))$
5. for any expression ϕ,
$T(\Pi, [A : \neg\phi]) \approx \lambda x : \neg[T(\Pi \setminus \neg, [A : \phi])](x)$
6. for any expression ϕ,
$T(\Pi, [A : \phi|\psi]) \approx \lambda x : (T(\Pi.A \setminus |, [A : \phi])(x) \veebar T(\Pi.A \setminus |, [A : \psi])(x))$
7. for every structure sharing marker $\boxed{\text{i}}$,
$T(\Pi, [A : \boxed{\text{i}}]) \approx \lambda x : A'(x) = z_i$
8. for any expression ϕ and structure sharing marker $\boxed{\text{i}}$,
$T(\Pi, [A : \boxed{\text{i}}\,\phi]) \approx \lambda x : A'(x) = z_i \wedge T(\Pi \setminus \boxed{\text{i}}, [A : \phi])(x)$

As an example, the FS (12) is translated (with simplification by λ-conversion) as:

(13) λx : move-events(x) $\wedge$ eventtimeperiod'(x) = past'(x) $\wedge$ agent-ref-domain'(x) = men' $\wedge$ agent-definiteness(x) = def' $\wedge$ ...

4.2 FS representation

The above semantics of FSs considers a feature structure to be semantically equivalent to a function that delivers true or false, i.e. to a characteristic function of a set of objects, or in other words, to a predicate. This means that we can embed FS in any representation language that has functions or predicates. For instance, reconsidering the sentence *Everyone will die*, where we have characterised the combination of the verbal construct *will die* with *everyone* as a FS describing a set of *die*-events, we may represent the complete declarative sentence as claiming the existence of an element in that set, and we may represent that as in (14):

$$(14)\quad \exists x : \begin{bmatrix} \textit{die\_events} & \\ \text{EVENTTIMEPERIOD} & \texttt{future}, \\ \text{AGENT-REF-DOMAIN} & \texttt{PEOPLE}, \\ \text{AGENT-REFDOM-INVOLVEMENT} & \texttt{total}, \\ \text{AGENT-DISTRIBUTION} & \texttt{individual}, \\ \text{SCOPING} & \texttt{<agent, event>} \end{bmatrix} (x)$$

By stipulating that the agents have scope over the events, we achieve a representation where the *die* events have narrow scope.

This example illustrates an important point to be noted about the kind of FS representations that we suggest for quantification: the entity that is claimed to exist in (14) is a *set of die-events*, not a single event; only by systematically relating verbs to sets of sets of events can we get the scopings between events and their 'participants' in the way we want.

For negative sentences, like *I didn't see anybody, I saw nobody*, or *Nobody died*, the negation should have sentence-level scope, leading to a representation like (14except for a negation that has scope over the entire formula.

In the examples of quantification considered so far, the various features had very simple values. For some features, such as definiteness and distribution, this is typically the case, but for other features, like reference-domain and the size or involvement indicating features, this need not be the case. The ISO proposal for FSs in XML includes proposals for representing numerical expressions like *more than 3, between 2.5 and 7.5*, and even *5 litres*, so we will assume the representing of complex size or involvement not to be a problem. A reference domain may also have a complex specification, like *students in this room.* To see how we can deal with that, we take a brief look at the representation of noun modification.

5 Noun modification

The semantics of modification has been studied much less than that of quantification, although it is a similar source of ambiguity. Consider, for instance, the parallel between sentences (15a) and (15b):

(15) a. The men moved the pianos.

b. The pianos that the men moved.

As in the quantification case, the modification in the second sentence can be taken collectively or individually: Were the pianos moved one by one or together? Were they moved by each of the men or by the men collectively?

The various aspects of quantification that we have considered evidently apply equally to modification by means of relative clauses, as in (15b), but they may turn up in other cases of noun modification as well. For instance, *heavy books* may refer to a set of heavy books or to a heavy set of books (*I'm carrying some heavy books*). Similarly, prepositional phrases are often equivalent to relative clauses, and thus having the same semantic aspects.

For what seems to be the most complex form of noun modification, that with a relative clause, we can devise a similar FS representation as for quantification. Two things are needed: (1) a kind of inverse notion of each semantic role (like agent, theme); we call these "inverse" attributes AGENT-EVENTS, THEME-EVENTS etc., and (2) a formal operator 'ex' to introduce a member of the value of a set-valued feature. Using these devices, we can represent (15b) as follows:

$$
(16)\quad \begin{bmatrix} \textit{pianos} & & \\ \textsc{theme-events} & \mathsf{ex}: & \begin{bmatrix} \textit{move\_events} & \\ \textsc{eventtimeperiod} & \texttt{past}, \\ \textsc{agent-ref-domain} & \texttt{MEN}, \\ \textsc{agent-definiteness} & \texttt{def}, \\ \textsc{agent-distribution} & \texttt{collective}, \\ \textsc{theme-ref-domain} & \texttt{PIANOS}, \\ \textsc{agent-distribution} & \texttt{individual}, \end{bmatrix} \end{bmatrix}
$$

As an example where noun modification is used inside a feature value in a quantification, consider (17) (with slightly compressed FS notation):

(17) a. Each of the 25 students in the room will present a paper.

b.
$$\left[\begin{array}{ll} \textit{present\_events} & \\ \text{EVENTTIMEPERIOD} & \texttt{future}, \\ \text{AGENT-REF-DOMAIN} & \left[\begin{array}{l} \textit{students} \\ \text{PREPOB-EVENTS} \\ \mathsf{ex}\left[\begin{array}{ll} \textit{in\_sits} & \\ \text{EVENTTP} & \texttt{present}, \\ \text{PREPOBRD} & \texttt{ROOMS}, \\ \text{PREPOBDEF} & \texttt{def-sing}, \end{array}\right] \end{array}\right] \\ \text{AGENT-DEFINITENESS} & \texttt{definite}, \\ \text{AGENT-REFDOM-SIZE} & \texttt{25}, \\ \text{AGENT-REFDOM-INVOLV.} & \texttt{total}, \\ \text{AGENT-DISTRIBUTION} & \texttt{individual}, \\ \text{THEME-REF-DOMAIN} & \texttt{PAPERS,} \\ \text{THEME-DEFINITENESS} & \texttt{indef} \\ \text{SCOPING} & \texttt{<agent, theme, event>}] \end{array}\right]$$

6 Concluding Remarks

In this paper we have suggested that it may be worth considering the possibility of using feature structures for the semantic representation of quantification and modification. Feature structures are a computationally attractive representation format, especially when use is made of the standard XML representation of feature structures that has recently been proposed by the international standards organisation ISO. Feature structures are not only computationally attractive, they are also theoretically attractive if it is correct to think that all cases of quantification and modification can be characterised in terms of a finite list of properties, for which feature structures are the theoretically simplest possible representation.

Even if the phenomena of quantification and modification would be too complicated to be adequately described by a finite number of properties, then still a feature structure representation would be of theoretical as well as practical interest, since the FS formalism naturally supports underspecification and allows the addition of properties should that be desirable, thus allowing the full meaning of the linguistic phenomena to be approached as closely as one may want.

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