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Semantic Annotation of Quantification in Natural Language

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Abstract

This paper proposes an approach to the semantic annotation of quantification in natural language. Its main purpose is to provide input for a project that aims to define an international standard that would be part of the ISO Semantic Annotation Framework (SemAF, ISO 24617). The proposed approach capitalizes on work in formal and computational semantics, notably on the theory of generalized quantifiers, on Discourse Representation Theory, and on neo-Davidsonian event-based semantics, and is compatible with the SemAF Principles of semantic annotation (ISO 24617-6:2016).

1 Introduction

Quantification phenomena occur in almost every sentence, and their interpretation is of central importance for correctly extracting information from a (spoken or written) text, but no annotation scheme has yet been proposed that deals with quantification phenomena in language in a general and semantically adequate way.

Quantification phenomena have not been covered by existing standards for semantic annotation. ISO standard 24617-1 for time and events has some provisions for dealing with time-related quantification; for example, the temporal quantifier "daily" is represented as follows, where the attribute @quant is one of the attributes of temporal entities, that may be used to indicate that the entity is involved in a quantification, and where "P1D" stands for "period of one day":

(1) <**TIMEX3 xml:id**="t5" **target**="#token0" **type**="SET" **value**="P1D" **quant**="EVERY"/>

ISO standard 24617-7 for spatial information also makes use of the @quant attribute, applying to spatial entities, and in addition uses the attribute @scopes to specify a scope relation. If the @scopes attribute in a <spatialEntity> element with @xml:id value *X* has the value *Y*, identifying another spatial entity, this means that the quantifier for *X* has scope over the quantifier for Y. The following example, taken from ISO 24617-7:2014, illustrates this (where 'EC' stands for 'externally connected'):

(2) A computer$_{se1}$ on$_{ss1}$ every desk$_{se2}$.

```
spatialEntity(id=se1, markable="computer", form=nom, countable=true,  quant="1",
        scopes=∅)
spatialEntity(id=se2, markable="desk", form=nom, countable=true, quant="every",
        scopes=se1)
spatialSignal(id=ss1, markable="on", semanticType=dirTop)
qsLink(id=qsl1, relType=EC, figure=se1, ground=se2, trigger=ss1)
oLink(id=0l1, relType="above", figure=se1, ground=se2, trigger=s1, frameType=intrinsic,
        referencePt=se2, projective=false)
```

This is intended to correspond to the following formula in predicate logic, which says that on every desk there is a computer (rather than that a certain computer is sitting on every desk):

(3) $\forall$se2 $\exists$se1 [[se2 $\in$ DESKS $\wedge$ se1 $\in$ COMPUTERS] $\rightarrow$ [EC{se2,se1) $\wedge$ ABOVE(se2,se1)]]

Temporal and spatial quantification, and quantification more generally, can however not be analysed in an adequate manner by means of attributes of temporal and spatial entities (see Bunt & Pustejovsky, 2010), since quantification phenomena are often not properties of the entities participating in a predication, but properties of *relations between them*, as discussed in the next section.

2 Basic concepts in the analysis of quantification

2.1 The nature of quantification

Quantification in natural language occurs whenever a predicate is applied to one or more sets of individual objects, as in (4) when "gave" is viewed as a 3-place predicate:

(4) Santa gave the children a present.

A singular noun phrase like "a present" might seem to refer to a single object, but this sentence most likely does not mean that Santa gave a single present to all the children, but rather that each one of a certain set of children was given a different present – so besides a set of children also a *set* of presents was involved. In technical terms, the quantification in the noun phrase "the children" has wider scope than the one in "a present". This can be brought out by the representations in predicate logic shown in (5), where (5a) is the reading in which "the children" have wider scope, and (5b) the one where "a present" has wider scope.

(5) a. $\forall$x [child(x) $\rightarrow$ $\exists$y [present(y) $\wedge$ give(santa,x,y)]]

b. $\exists$y present(y) $\wedge$ $\forall$x [child(x) $\rightarrow$ give(santa,x,y)]

Relative scope is one of the most important and most studied aspects of quantification in natural language (see e.g. Montague, 1971; Cooper, 1983; Kamp & Reyle, 1993; Szabolcsi, 1997; 2008; Winter & Ruys, 2011). The annotation of scope is discussed in Section 6.3. The semantic annotation of quantification in natural language is more generally concerned with specifying the precise way in which a predicate is applied to one or more sets of arguments.

Quantification has been studied extensively in logic (Aristotle; Frege, 1879; Tarski, 1936; Mostowski, 1957; Lindström, 1966); in linguistics (Higginbotham & May, 1981: Keenan & Stavi, 1986; Zwarts, 1984; Partee, 1988; Szabolcsi, 2010; Winter & Ruys, 2011), in formal semantics (Montague, 1974; Barwise & Cooper, 1981; van Benthem, 1984; Westerståhl, 1985; Kamp & Reyle, 1993), and in computational semantics (Alshawi, 1990; Bos, 1995; Hobbs & Shieber, 1987; Pinkal, 1999; Pulman, 2000). In logic, the study of quantification and its role in formal reasoning has long been restricted to the universal ($\forall$, 'for all') and existential ($\exists$, 'for some') quantifiers. Fairly recently (see Mostowski, 1957; Lindström, 1966), it was noted that the universal and the existential quantifier can both be viewed as expressing a property of sets of individual objects, involved in a predication: the universal quantifier expresses the property of being a set that contains all the elements of a given domain; the existential quantifier the property of containing at least one of these elements. Moreover, this notion of a quantifier has been generalised to other properties of sets, such as the properties that in English can be expressed by "most", "less than half of", "three", or "more than 200". The concepts in this broader class of quantifiers are called *generalized quantifiers*.

The study of generalized quantifiers, as expressed in natural language, has led to *generalized quantifier theory*. This theory acknowledges the existence of a fundamental difference between quantification in natural language and quantification in logic. Words like "all" and "some" in English, as well as their equivalents in other languages, may seem to be the counterparts of the universal (∀, 'for all') and existential (∃, 'for some') quantifiers of formal logic, and words like "three", and "most", which have been called 'cardinal quantifiers' and 'proportional quantifiers' (Partee, 1988), may seem to be the counterparts of certain generalized quantifiers, but this is not the case. In formal logic, if p is a formula that denotes a proposition then the expressions '∀x. p' and '∃y. p' are quantifications, saying that p is true of all individual objects and that p is true of at least one such object, respectively.

Such quantifications, which range over all individual objects in a universe of discourse, cannot be expressed in natural languages. It just is not possible to say that something is true "for all" or "for some", where "all" and "some" would refer to any conceivable object. The English expressions that are closest to the universal and existential quantifiers of formal logic are "everything", "everybody", "something" and "somebody" (and similarly in other languages), but these expressions do not quantify over *all* entities, but only over things and persons, respectively. Instead, natural languages have quantifying expressions like "all politicians", "a present", "some people", and "more than five sonatas", which include the indication of a certain domain that the quantification is restricted to. This has led to the view that quantifiers in natural language are not determiners like "all" and "some", but are noun phrases (Barwise and Cooper, 1981). Determiners, instead, denote mappings from sets of entities to logical quantifiers (properties of sets of individuals).

Some aspects of the meaning of a predication can be accounted for only if verbs are viewed as introducing sets of events (in a broad sense of 'event', that includes states, processes, ...), rather than as predicates. For example, the past tense of the verb form "gave" in sentence (4) indicates that the give-events referred to occur in the past. This can be expressed in a first-order predicate logic representation by introducing an additional argument in a predicate, as in (6a), or by introducing a one-place verb-derived predicate whose argument is copied in the use of binary predicates that represent semantic roles, as in (6b).

(6) a. $\forall x\ [child(x) \rightarrow \exists y\ \exists e\ [present(y) \wedge give(e,santa,x,y)] \wedge past(e)]$

b. $\forall x\ [child(x) \rightarrow \exists y\ \exists e\ [present(y) \wedge give(e) \wedge agent(e,santa) \wedge theme(e,y) \wedge beneficiary(e,x)]]$

Representation (6a) can be read as: for each child x there is a present y and an event e such that in that event Santa gave y to x, and the event occurred in the past. Representation (6b) can be read as: for each child x there is a present y and a "give"-event e with Santa as the agent, x as the beneficiary, and y as the object that was given. The latter kind of representation, which corresponds to what is known in the literature as the neo-Davidsonian approach, following

Davidson (1967) and Parsons (1990), makes the semantic roles explicit of the participants in an event (as defined in ISO 24617-4) and has the advantage that it allows the representation of certain quantification aspects, such as the collective/individual distinction discussed below, as a property of the way in which a set of participants is involved in an event. Moreover, this representation is compatible with the annotation of semantic roles according to ISO 24617-4, which would look as in (7):[1]

(7)
```
<event xml:id=”e1” target=”#m2” pred=”give”/>
 <entity xml:id=”x1” target=”#m1” entityType=”santa”/>
 <srLink event=”#e1” participant=”#x1” semRole=”agent”/>
 <entity xml:id=”x2” target=”#m3” entityType=”child”/>
 <srLink event=”#e1” participant=”#x2” semRole=”beneficiary”/>
 <entity xml:id=”x3” target=”#m4” entityType=”present”/>
 <srLink event=”#e1” participant=”#x3” semRole=”theme”/>
```

The interpretation of expressions such as “twice” (as in “I called you twice”) and “more than five times” also require the introduction of sets of events, since they indicate the number of events of a certain type. Similarly for expressions of frequency, such as “twice every day” in “I will call you twice every day”.

The present annotation standard takes an approach which combines generalized quantifier theory with the neo-Davidsonian event-based approach, including the use of semantic roles as defined in ISO 24617-4.

2.2 Quantification domains: Source and reference domain

Noun phrases (NPs), expressing (generalized) quantifiers in natural language, typically consist of two parts: (1) a noun, in grammatical analysis called the ‘head’ of the NP, possibly with one or more adjectives, prepositional phrases or other modifiers, and (2) one or more determiners such as “a”, “the”, “all”, “some”, “most”, “half of the”, and “less than 200”. The head noun with its modifiers is called the ‘restrictor’ of the quantifier and indicates a certain domain that the quantifier ranges over. The term *source domain* is used to indicate the set of entities (or, alternatively, the property that characterises these entities; see Gawron, 1996) that the restrictor refers to. The presence of a restrictor component forms the fundamental difference between quantification in logic and quantification in natural language, mentioned above: quantification in logic is always understood as ranging over the set of all entities in a given universe of discourse, whereas quantification in natural language is restricted to a source domain that is made explicit in the quantifier’s restrictor. (Section 6.6 below discusses the syntax and semantics of complex restrictors.)

While linguistically restricted to a certain source domain, quantification is often intended to be further restricted to a particular part of that domain. For example, a teacher who uses the sentence (8) in class does not mean to put an obligation on every person, but only on the students who participate in a particular course.

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[1] The XML representation specified in ISO 24617-7 uses an XML element called ‘eventuality’ with an attribute `eventFrame’; instead the notation of ISO 24617-1 is used here, with its ‘event’ element and ‘pred’ attribute.
[2] See e.g. Kramsky (1972) on the expression of definiteness in large number of languages.

(8) Everybody must hand in his essay before Thursday next week

Similarly, in example (9), "all the twenty-seven member countries" refers to a specific subset of the source domain designated by "countries". The use of the definite determiner forms an indication that this subset, of cardinality 27, is the contextually determined reference domain of the quantification.

(9) The proposal was accepted by all the twenty-seven member countries.

Westerståhl (1985) introduced the term `context set' to designate contextually determined subsets of a source domain that are relevant in a quantified predication. Partee et al. (1990) characterize the role of a context set by saying that 'restriction to a context set serves to represent which elements of the large domain of entities have been contextually given', where the 'large domain of entities' corresponds to what in this document is called the 'reference domain'; Moltmann (2006) relates reference domains to the definiteness of NPs: 'Definite NPs presuppose their domain', as illustrated in (9), where the numerical expression like "twenty-seven" expresses a presupposition about the size of the quantifier's reference domain. See also Section 6.3 below on the definiteness of NPs. A quantifier's reference domain is in general determined by the familiarity, salience, recent mention, physical presence, and other contextual considerations that make some elements of the source domain more plausible participants in the events being considered.

Whereas a reference domain is context-dependent by its very nature, a source domain, by contrast, is typically determined by the restrictor in an NP. An NP may however happen not to contain any restrictor, as in (10), in which case the source domain is determined mainly by the context.

(10) a. Some like it hot.
b. Do all agree?

The source domain in these examples is largely determined by the possible complements of "Some" and "all", and partly also by the possible subjects of the verbs "like" and "agree", but an accurate determination is not possible in such cases ("persons" might be a good guess). The reference domain in (10a) is presumably the same as this source domain, and in (10b) it is the set of those persons that are present at a certain meeting, except for the speaker.

The restrictor part in a full-fledged NP contains minimally a noun and possibly other expressions that modify the noun, such as adjectives, other nouns, (as in "bread crumbs"), prepositional phrases or relative clauses. The consequences of the presence of modifiers in the restrictor part are considered in Section 6.6. The determiner part may be a sequence of determiners of different types, distinguished by sequencing and co-occurrence restrictions. For example, in English grammar it is customary the make a distinction between predeterminers, central determiners, and postdeterminers (see e.g. Quirk et al., 1972; Leech and Svartvik, 1975; Bennett, 1987). This classification can be applied in such a way that the determiners in each class have a different function (Bunt, 1985):

- predeterminers express the (absolute or proportional) quantitative involvement of the reference domain, and may, in addition, say something about the distribution of a quantifying predicate over the reference domain – see Section 6.3;
- central determiners express the definiteness of the NP;
- postdeterminers express a proposition about the cardinality of the reference domain.

This is illustrated by the NP "All my nine grandchildren" in (11), where "all" is a predeterminer, "my" a central determiner, "nine" a postdeterminer, and "grandchildren" a restrictor.

(11) All my nine grandchildren are boys.

Quantification over time and space is also expressed in natural language by means of adverbs, such as "always", "sometimes", "never", "annually", "everywhere", "somewhere" and "nowhere".

2.3 Definiteness

Definiteness and its marking is a language-dependent issue; in English and in most European languages it is marked most clearly by the use of a definite article and/or a nominal suffix, such as "*the book*" in English, *"bogen"* in Danish, and *"o livro"* in Portuguese.[2] Besides NPs with a definite determiner, other expressions that are also considered to be grammatically 'definite' include NPs with a possessive pronoun ("my house") or genitive ("Mary's dog") or with a demonstrative pronoun ("those shoes") as well as universal quantifiers (see (8) above).[3]

The meaning of definite expressions is the subject of a vast amount of literature (see e.g. Von Heusinger, 2011; Abbott, 2017) with alternative approaches and theories. The semantic difference between definite and indefinite expressions has been discussed in terms of familiarity and novelty (e.g. Heim, 1982), salience, uniqueness, and existence presuppositions (see e.g. Coppock and Beaver, 2015). The familiarity/salience intuition about definite NPs can be accommodated in a GQT framework by assuming the reference domain of a quantification to contain familiar or particularly salient entities.

Definite expressions have been claimed to differ from indefinite and explicitly quantified expressions in having the function to *refer* to certain entities, rather than to *quantify* over them (Frege, 1892). This has been argued to be a false opposition (e.g. Szabolci, 2010; Abbott, 2017), for example in view of the semantic similarity between the 'referential' NP in (12a) and the 'quantificational' one in (12b). GQT offers a way of dealing with all kinds of definite NPs, including proper names.

(12a) The committee members went out to lunch

(12b) All of the committee members went out to lunch

Two much debated issues concerning definitess, which are important for a GQT-based approach to their interpretation, concern whether the entity that a singular definite NP (with a count noun as head) refers to is claimed (1) to exist and (2) to be uniquely determined. Russell (1905) analyses the sentence "The king of France is bold" as saying that there is a unique person who is the king of France and who is bold. Alternatively, the sentence has been analysed as saying that the king of France is bold if there exists exactly one king of France, and as being meaningless otherwise (Strawson, 1950). Coppock and Beaver (2015) argue that the latter view is correct for NPs used as arguments of a verb, which corresponds to NPs used as quantifiers over participants in events (but not correct for (negated) predicative NPs, i.e. NPs used in combination with a copula to construct a predicate (within the scope of a negation), in which case the existence assumption does not hold). Indefinite NPs (singular or plural), definite plural NPs, and mass NPs differ from definite singular NPs

[2] See e.g. Kramsky (1972) on the expression of definiteness in large number of languages.
[3] See Zwarts (1994) for a brief overview of so-called definite expressions and Abbott (2017) for a survey of issues relating to referring expressions.

in not carrying a uniqueness assumption, but when used to quantify over event participants they all carry an existence presupposition.[4] This will be reflected in the semantics of the proposed annotations by the use of discourse referents that designate non-empty sets.

2.4 Distribution

The distribution (or 'distributivity') of a quantification expresses whether a predicate applies to a set of arguments as a whole, to the members of that set individually, or to certain subsets. The examples in (13) illustrate this ambiguity; in the first sentence the more likely interpretation is that the two men together carried the piano, i.e. they acted collectively, whereas in the second sentence it is more likely the case that each of the men individually carried some vegetables.

(13) a. Two men carried a piano upstairs.

b. Two men carried some vegetables to the kitchen

The distinction between collective and individual readings can be brought out by a representation in second-order predicate logic, as shown in (14).

(14) a. $\exists X\ [\ |X|=2 \wedge \forall x\ [x \in X \rightarrow man(x)] \wedge \exists y\ \exists e\ [piano(y) \wedge carry(e) \wedge agent(e,X) \wedge theme(e,y)\ ]]$

b. $\exists X\ [\ |X|=2 \wedge \forall x\ [x \in X \rightarrow man(x)] \wedge \forall y\ [y \in X \rightarrow \exists e\ \exists z\ [vegetable(z) \wedge carry(e) \wedge agent(e,y) \wedge theme(e,z)\ ]]]$

Representation (14a) reads as follows: there is a set X of cardinality 2, which consists of men, and there is a piano y and a carry-event e such that the set of men X is the agent of that carry-event e and the piano y is the theme of that event. Representation (14b) reads: there is a set X of cardinality 2, which consists of men, and for each member y of this set there are some vegetables z and a carry-event of which y is the agent and z is the theme.

There is more to the distribution of a quantification than just the distinction between collective and individual (also called 'distributive'). Consider sentence (15a), which is structurally very similar to (13a), uttered in a context where the promise expressed in (15b) had been made:

(15) a. The boys carried all the boxes upstairs

b. If you carry all these boxes upstairs today I'll give you an ice cream tonight.

Despite their structural similarity, (15a) is not ambiguous in the same way as (13a) for in the context established by (15b) the speaker does not want to suggest that the three boys designated by "you" in (15b) should do all the carrying either collectively or individually; rather the intention is that the three boys should *somehow* get all the boxes upstairs, irrespective of whether they do it collectively, individually, or in other ways; the sentence could for instance describe a set of events in which the three boys collectively carried the heaviest boxes, and individually the lightest ones (maybe even several very light ones in one go), while pairs of boys together carried the boxes of medium weight. This means that the distribution of the quantification over the set of three boys is neither collective nor individual; the term 'unspecific' has been used for this distribution (Bunt, 1985).

[4] There are cases of the use of a singular definite NP without a uniqueness assumption, which are a cause of ongoing debate. Body parts are a notorious case: a sentence like "I squeezed Lola's hand" presumably does not imply that Lola has only one hand. See e.g. Coppock & Beaver (2015), Sect. 2.3.

Following Kamp & Reyle (1993), the notation X* is used in this document to designate the set consisting of the members of X and the subsets of X, and if P is a predicate applicable to the members of X, then P* designates the generalization of P that is applicable also to subsets of X. In particular, if P_X is the characteristic function of the set X, then P_X* designates the characteristic function of X*. Using this notation, and moreover using the notation R_0 to indicate the characteristic function of a reference domain that is part of a source domain with characteristic function R, the intended interpretation of (15a) can be represented in second-order predicate logic as follows:

(16) $\forall x\, [box_0(x) \rightarrow \exists y\, \exists e\, [boy_0*(y) \wedge carry\text{-}up(e) \wedge agent(e,y) \wedge \exists z\, [box_0*(z) \wedge [x=z \vee x \in z] \wedge theme(e,z)]]]$

This representation says that for every box x in a given reference domain of boxes, there is a carry-event in which either an individual contextually distinguished boy or a group of such boys carried that box x upstairs or carried a set of boxes upstairs that contains x.

Besides the 'unspecificity' in (15a), where both individual objects and sets of individual objects may be involved, there is also another form of unspecificity where *parts of individual objects* may be involved, as illustrated by (17a). This sentence could for example describe a series of events where last Monday Mario had a pizza, last Wednesday he had one and a half pizzas, and on Friday he had the remaining slices from Wednesday. Pizzas are a domain where the individuals are clearly divisible, and where it is common to consider parts of individuals. The same is true for many other domains related to food and drink. For some other domains this is less common, but in principle every physical object has parts, and many abstract objects as well. Whether a quantification should take parts of individuals into account is a context- and domain-dependent issue, but when interpreting an NP that describes domain involvement or size in terms of a non-integer number of individuals, this is clearly necessary. The interpretation of sentence (17a) as describing a set of events in which Mario has eaten some pieces of pizza, adding up to a total of three pizzas, can be represented by (17b), where the notation 'P^' is used to designate the property of being a part of an individual that has the property P, and 'Σ^' designates the joining together of parts of an individual. Representation (17b) says that there is a set (Y) of pizza parts that were involved as the theme in an eat-event with Mario as the agent, and those parts joined together make up a set of cardinality 3.[5]

(17) a. Mario had three pizzas last week.

b. $\exists Y\, [\, \forall y\, [y \in Y \rightarrow [pizza\hat{}(y) \wedge \exists X\, [|X| = 3 \;\wedge\; [x \in X \rightarrow [pizza(x)] \wedge \; \Sigma\hat{}(Y) = X] \wedge$
$\exists E\, [e \in E \rightarrow [eat(e) \wedge agent(e,Mario) \wedge theme(e,y)]]]]]$

The distribution of a quantification is not a property of a set of participants in a set of events, but a property of the way of participating. This is illustrated by example (18a). Presumably, each of the men mentioned in (18a) individually had a beer, and collectively carried the piano upstairs. This cannot be accounted for by treating the NP *"the men"* as referring to either a set of individual men or to a collective of men. The distribution of a quantification should thus be marked up on the

[5] Expressing the size of a collection of pizza-parts in terms of number of pizzas is speaking as if all pizzas have the same size. For example, four quarts of four different pizzas together have a size of 2 pizzas, even though the four parts cannot physically be joined to form two well-formed pizzas. The join operator 'Σ^' corresponds to the more abstract idea of joining parts of individuals.

relation that describes the participation of the men in the drink- and carry- events, as in the annotation fragment shown in (18b), where the XML element ‘srLink’, defined in ISO 24617-4, has been extended with the attribute ‘distr’:

(18) a. The men had a beer before carrying the piano upstairs.

b.
```
<entity xml:id=”x1” target=”#m1” entityType=”man”/>
<event xml:id=”e1” target=”#m2” pred=”drink”/>
<event xml:id=”e2” target=”#m3” pred=”carry”/>
<srLink event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”/>
<srLink event=”#e2” participant=”#x1” semRole=”agent” distr=”collective”/>
```

Collective distribution in a quantification in natural language can be expressed my means of adverbs, like *“together”, “ensemble”* (French), and “samen” (Dutch); individual distribution can also be expressed by adverbial expressions, like *”one by one*”, but in contrast to collective distribution, individual distribution can also be expressed by the choice of determiner: “*each*” in English, “*chaque*” in French, and “*jeder*” in German all express individual participation. Note that, if in sentence (18a) *“The men”* is replaced by *“Each of the men”,* then the interpretation where the men individually had a beer and collectively carried the piano upstairs is no longer available; the men are now understood to individually carrying the piano upstairs. Some determiners, such as the English *“each”, “all”,* and “*both*” can also be used as adverbs, as in *“They are all farmers”, “The man had a beer each”,* and *“They both looked happy”*; this phenomenon is known as ‘quantifier floating’ (see e.g. Kamp & Reyle, 1993).

2.5 Size and cardinality

Cardinal determiners indicate the cardinality or size of a set; in (19), the central determiner *“twenty-seven”* designates the cardinality of the reference domain, while the predeterminer *“twenty-five”* designates the cardinality of the subset of the reference domain whose members were actually involved in vote-events. In (13a) above, the determiner “two” designates the size of a group of men collectively involved in an event.

(19) Twenty-five of the twenty-seven member states voted in favour.

So at least the following quantitative aspects of a quantification should be taken into account: (1) the cardinality of the reference domain; (2) the number of elements in the reference domain involved in the predication; and (3) the size of groups of individual objects that are involved in a collective predication.

With respect to the latter quantitative aspect, it may be noted that in example (13a) the numeral “two” can be taken to indicate *both* group size and amount of involvement, assuming that only one group of men is involved. In (20), which is almost the same as (13a), only the group size interpretation of “three” remains (on the reading where the two pianos were moved by different groups of men). Incidentally, the numeral “two” in (13a) also allows us to the infer that the amount of involvement is 2, like in (20) it can be inferred that at least three and at most six men are involved.

(20) Both pianos were carried upstairs by three men.

Sentence (20a) illustrates the use of a cardinal determiner to indicate the cardinality of groups of elements from the reference domain that collectively participate in a set of events. This interpretation of a cardinal determiner can be represented in predicate logic as shown in (21b) if events are treated as individual entities. This can be annotated as in (21c), where the XML element 'entity' has been enriched with attributes for marking up definiteness and number of entities involved, and the srLink element with an attribute 'size'.

(21) a. This assembly machine combines 12 parts.

b. $\forall e$ [[combine(e) $\wedge$ agent(e,m_0)] $\rightarrow$ [$\exists X$ |X|=12 $\wedge$ $\forall x$. [X(x) $\rightarrow$ [part(x) $\wedge$ theme(e,X)]]]

c.
```
<entity xml:id="x1" target="#m1" entityType="assembly-machine"
        definiteness="definite" involvement="1"/>
<event xml:id="e1" target="#m2" pred="combine"/>
<srLink event="#e1" participant="#x1" semRole="agent" distr="individual" size="12"/>
<srLink event="#e1" participant="#x1" semRole="theme" distr="collective"/>
```

For a quantification with individual distribution, the involvement of the reference domain *D* can be expressed in terms of number of elements of *D*, and in the case of collective distribution, the size of collectively participating sets of domain members can be measured in the same way. In the case of unspecific distribution, where also parts *D*-elements may be involved, one finds expressions of involvement like the one in (22).

(22) Mario ate two and a half pizzas.

In this case the involvement of the reference domain can be computed by taking for each part 'p' of an individual 'd' the fraction of 'd' that it forms, which is a nonnegative rational number between 0 and 1, and by adding up these numbers for all the parts that participate in the events.

2.6 Scope

The relative scoping of quantifications over sets of participants, already adumbrated in Section 6.1, can be illustrated by the classical example of scope ambiguity in (23), where one interpretation is that the NP "Everyone in this room" has wider scope than the NP "two languages", so that the sentence says that each of the people in the room masters two languages; which two languages may differ from person to person, and the other interpretation is that the two languages are the same for everyone.

(23) Everyone in this room speaks two languages.

Quantifier scope ambiguities are a nightmare from a computational point of view: a sentence with k noun phrases may have k! possible interpretations due to alternative scopings alone, although syntactic constraints reduce this number. Hobbs and Shieber (1987) have shown that a sentence with the syntactic structure of (24), containing five NPs, and thus having 5! = 120 (=5x4x3x2) potential scopings, has in fact 'only' 42 valid alternative scopings – which is still a formidable number, the more since quantifier distribution ambiguities form an independent (and even richer) source of ambiguities.

(24) Some representatives of every department in most companies saw a few samples of every product.

Studies of relative scope in quantifying expressions have been focused almost exclusively on the relative scopes of sets of participants. However, when sets of participants are involved in a *set* of events rather than in a single event, the relative scoping of participants and events is also an issue. This is illustrated by the two possible readings of the sentence in example (25):

(25) Everyone will die.

Besides the reading that comes down to saying that everyone is mortal, which can be represented in predicate logic as $\forall x\ [\text{person}(x) \rightarrow \text{will-die}(x)]$, or as in (26a) using explicit events, there is also a reading which predicts an apocalyptic future event in which everyone will die. (Note that this interpretation requires the consideration of events in which multiple participants occupy the same role. The ISO approach to semantic role annotation (ISO 24617-4), does allow multiple participants to have the same semantic role.)

There is no way to represent this second reading without explicitly introducing events; (26a) and (26b) show how both readings can be represented in first-order logic by assigning alternative relative scopes to the quantifications over events and participants:

(26) a. $\forall x\ [\text{person}(x) \rightarrow \exists e\ [\text{die}(e) \wedge \text{future}(e) \wedge \text{theme}(e,x)]]$

b. $\exists e\ [\text{die}(e) \wedge \text{future}(e) \wedge \forall x\ [\text{person}(x) \rightarrow \text{theme}(e,x)]]$

Quantifications over events tend to have narrow scope, but this is a context-dependent issue, as the examples in (27) illustrate. The interpretation of (27a) as describing a single event with multiple participants corresponds to the annotation in (27b), where the XML element 'srLink' has been enriched with the attribute 'evScope' to indicate the relative scope of the events and the linked participants.

(27) a. All passengers died [in the crash].

c. <entity xml:id="x1" target="#m1" entityType="passenger" involvement="all"/>
<event xml:id="e1" target="#m2" pred="die" time="past"/>
<srLink event="#e1" participant="#x1" semRole="theme" distr="individual"
evScope="wide"/>

There are cases where none of the quantifications over one set of participants has wider scope than the other. An example is so-called 'cumulative' quantification (Scha, 1981), as illustrated in (28) (due to Reyle, 1993):

(28) Three breweries supplied fifteen inns.

The intended reading here is not that each one of three breweries supplied each one of fifteen inns (wide scope of *"three breweries"),* nor that each one of fifteen inns was supplied by each of three breweries (wide scope of *"five inns"),* but rather that there is a group A of three breweries and a group B of fifteen inns, such that the members of A supplied members of B, and that the members of B were supplied by members of A. In this case, the two quantifications can be said to have equal scope. This is an instance of so-called ‘branching quantification’ (Hintikka, 1973; Barwise, 1979; Sher, 1997), i.e. the phenomenon that a sentence contains two or more quantifiers of which the scopes are only partially ordered. Sher (1997) calls the case of cumulative quantification ‘independent branching quantification’, since in this case each quantifier is semantically independent of the other quantifier(s).

The sentence in (30a) has the same syntactic form as the one in (29), but here the intended reading is not cumulative; it is from a report about a tournament of (European) football where teams of boys and teams of girls participated, and whenever a team of boys played against a team of girls, its size would be reduced from 11 to 7. This is expressed in predicate logic in (30b) The two cardinal determiners are indicators not of reference domain involvement but of group size associated with the collective participation of boys and girls. The quantifications over boys and girls do not differ in scope and require a special treatment of the cardinal determiners (see Appendix C; the scope relation in this case is called ‘unscoped’).

(30) a. Seven boys played against eleven girls.

b. $\forall e\ \forall X\ \forall Y\ \ [[play(e) \wedge \forall x\ [X(x) \rightarrow boy(x)] \wedge \forall y\ [Y(y) \rightarrow girl(y)] \wedge agent(e,X) \wedge$

$agent(e,Y] \rightarrow [|X|=7 \wedge |Y|=11]]$

In summary, a cardinal determiner indicates the size of a set – of exactly which set is determined by the scope of the quantifier expressed by the NP relative to those of other quantifiers in the same clause and by whether the entities of the quantifier’s reference domain participate collectively or individually in the clause’s events.

2.7 Structured quantification domains

Quantification in natural language has been studied mostly in relation to the semantics of noun phrases (NPs) and their combination with verb phrases. Quantification phenomena arise also when an adjective is applied to a set of arguments. For example, the sentence in (31) is ambiguous between a reading in which “these books” as a whole are heavy (collective reading), and a reading in which each of “these books” is heavy (distributive reading). By analogy with the predicate logic representation of distributive and collective readings of quantified verb arguments, these readings can be analysed semantically in terms of participation in a set of events (mostly of a static kind), as shown in the representations (32a) and (32b)[6], respectively, which opens the way for dealing with questions of the distribution of the participation and the relative scope of events and participants. Alternatively, the simpler (but slightly less expressive) representations in (32c, d) can be used, with a one-place predicate constant corresponding to the adjective, rather than a set of events, since questions of scope do not arise in adjectival modification. As in (15) above, the notation with a subscript ‘0’ as in ‘$book_0$’ is used here to indicate that the reference domain of the phrase “these

[6] The use of the ‘theme’ role to connect the argument and the state denoted by the adjective in this analysis is justified by the definition of this role in ISO 24617-4, which stipulates that a participant in an event or state has this role *if it is central to the event/state; it is essential for the event/state to occur/hold; and it is not structurally changed by the event/state*.

books" is formed not by the source domain of all books, but rather to some specific set of books, determined by the context and indicated by the demonstrative "these".

(31) These books are heavy.

(32) a. $\exists X\ [\forall x\ [x \in X \leftrightarrow [\mathrm{book}_0(x) \wedge \exists e\ [\mathrm{heavy}(e) \wedge \mathrm{theme}(e,x)]]]]$

b. $\exists X\ [\forall x\ [x \in X \leftrightarrow \mathrm{book}_0(x)] \wedge \exists e\ [\mathrm{heavy}(e) \wedge \mathrm{theme}^*(e,X)]]$

c. $\exists X\ [\forall x\ [x \in X \leftrightarrow [\mathrm{book}_0(x) \wedge \mathrm{heavy}(x)]]]$

d. $\exists X\ [\forall x\ [x \in X \leftrightarrow \mathrm{book}_0(x))] \wedge \mathrm{heavy}^*(X)]$

Example (31) illustrates the predicative use of an adjective; the attributive use is illustrated in (33), which displays the same ambiguity as the predicative use in (31). Predicate logic representations of the two readings are shown in (34) (on the interpretation where the books were carried collectively).

(33) Peter carried the heavy books upstairs.

(34) a. $\exists X\ [\forall x\ [x \in X \leftrightarrow [\mathrm{book}_0(x) \wedge \mathrm{heavy}(x) \wedge \exists e\ [\mathrm{carry}(e) \wedge \mathrm{agent}(e,peter) \wedge \mathrm{theme}^*(e,X)]]]$

b. $\exists X\ [\forall x\ [x \in X \leftrightarrow \mathrm{book}_0(x)] \wedge \mathrm{heavy}^*(X) \wedge \exists e\ [\mathrm{carry}(e) \wedge \mathrm{agent}(e,peter) \wedge \mathrm{theme}^*(e,X)]]$

The individual/collective ambiguity of (31) and (33) is due to an ambiguity in the way the predicate is applied to its arguments. Upon the predicate view of adjectives corresponding to (32c, d) this could be annotated as in (36):

(35) heavy books

(36)
```
<entity id="x1" target="#m2" pred="book"/>
<entity id="x2" target="#m1 pred="heavy"/>
<adLink head="#x1" mod="#x2" distr="collective" />
```

Note that an attributive adjective occurs in the restrictor part of an NP, and as such contributes to the determination of a source domain for quantified predication. Such a role can be played not only by adjectives but also by nouns, prepositional phrases (PPs), and relative clauses (RCs), as illustrated by the NPs in (37), showing restrictors that contain adjectives (37a-f), nouns (37d), prepositional phrases (37e), and relative clauses (37f-g).

(37) a. Thirty-two Chinese students enrolled.

b. Alex showed me two of his rare Chinese books.

c. Jim was carrying some heavy books.

d. Alice showed me her beautiful archaeology books.

e. Alex showed me two rare books from China.

f. Alex showed me two rare books printed in Hong Kong.

g. Alex showed me two books that he'd bought in an antique shop in Chengdu.

The modification of a noun by another noun is different from modification by an adjective, in that the modifying noun can in general not very well be regarded as a predicate. Rather, the modifying noun denotes a concept or a property defining a set of concepts to which the denotation of the modified noun has some implicit semantic relation, like *instrument-for, purpose-of, used for, obtained-from*, or *location-of*, as the following examples illustrate:

(38) university diplomas, archaeology books, garbage can, piano music, smoking ban, dining car, sleeping compartments, truck drivers, council members

Hobbs et al. (1993) have proposed a treatment of noun-noun modification in predicate logic by introducing a metavariable 'NN' that is to be instantiated by a semantically appropriate two-place predicate through abductive reasoning, exploiting context information. For example, the nominal compound "Boston office" in (39a) is represented as (39b). The variable NN can in this example be instantiated as *Located-in*.

(39) a. The <u>Boston office</u> called.

b. office(x) ∧ boston(y) ∧ NN(x,y)

Modification by PPs, as illustrated by the examples in (40), bears some semantic similarity to noun-noun modification in the case of simple PPs, as the similarity of the representations (39b) and (40b) illustrate; the difference is that in the case of PP modification the preposition gives an indication (albeit in a rather vague and ambiguous way) of how the entities denoted by the head noun are related to certain other entities.

(40) a. books <u>from Hong Kong</u>.

b. book(x) ∧ hongkong(y) ∧ from(x,y)

As in the case of modification by an adjective, the modification by a PP can be distributive or collective. This is illustrated by example (41), which reproduces a text that was seen next to a box of bell peppers:

(41) Bell peppers for fifty pesos

This text is ambiguous as to whether the PP *"for fifty pesos"* indicates that the bell peppers in the box cost 50 pesos apiece (individual reading) or that the whole content of the box costs 50 pesos (collective reading). Note that the plural NP *"fifty pesos"* should be treated as denoting a single entity, an 'amount' (of money), in the sense discussed in Section 6.7.

A fundamental difference between PP modification on the one hand and adjectival and noun-noun modification on the other, is that the embedded NP, which is linked to the modified head by a preposition, can be arbitrarily complex. In particular, if the embedded NP is a quantifier (rather than a referential expression, as in (40)), the question arises of how this quantifier is scoped relative to the quantifiers in the main clause. Scope ambiguities may occur in PP-modification with individual distribution because a distributive modifier expresses a quantifying predicate that is applied to the entities denoted by the NP head, and this quantifier may have wider scope than a quantifier in the main clause, as illustrated in (42a). On the most plausible reading of this sentence, the quantifier *"every city that … in the plan"* takes scope over the existential quantifier *"a council member"*. This phenomenon is known as 'inverse linking' (May, 1977; May and Bale, 2007; Ruys and Winter, 2011;

Barker, 2014). The predicate logic representations in (42b, c) show the reading with inverse-linking and the implausible reading without inverse linking, respectively.

(42) a. President Kay met with a council member from every city that took an interest in the plan.

b. $\forall y\ [city(y) \rightarrow \exists x\ [council\text{-}member(x) \wedge from(x,y) \wedge meet(kay,x)]]$

c. $\exists x\ [council\text{-}member(x) \wedge \forall y\ [city(y) \rightarrow from(x,y)] \wedge meet(kay,x)]$

If the sentence in which the PP-modified NP occurs contains more than one quantifier, then the quantifier of the embedded NP may also take scope over more than one quantifier. This is illustrated in (43), where a universally quantified NP (*"every man from a small town in Alaska"*) contains an existentially quantified embedded NP (*"a small town in Alaska"*) in a PP. The inversely linked reading shown in (43b) seems more prominent than readings where the embedded quantifier has narrow scope.

(43) a. Recruiters approached every man from a small town in Alaska.

b. $\exists y\ [smalltown(y) \rightarrow [\forall x\ [man(x) \wedge from(x,y)] \rightarrow \exists z\ [recruiter(z) \wedge approach(z,x)]]]$

Inverse linking may also occur in the modification by a relative clause (RC), but much less so than in PP-modification due to the fact that RCs are so-called `scope islands' (Rodman, 1976), which has the effect that many quantifiers can only take scope over other quantifiers *inside* the RC. This is illustrated by the contrast between the following sentences (from Barker, 2014):

(44) a. A woman from every borough spoke.

b. A woman who is from every borough spoke

The sentence with PP modification has an interpretation with inversely linked scopes (in fact this interpretation is strongly preferred), which the sentence with RC modification does not have.[7]

When an NP head is modified by an RC the entities denoted by the NP head participate in two events: in the one described in the main clause and in another one described in the RC. For the participation in the latter event, issues of distribution and scope arise, as the example in (45a) illustrates.

(45) a. The huge tubes (that were) moved by those cranes.

b. Those cranes moved five huge tubes.

The NP of (45a) is ambiguous in the distributive aspect of the quantification in *"the huge tubes*", in the same way as in sentence (45b): Were the pipes moved one by one (individual reading) or all in one go (collective reading); Did the cranes individually move the tubes or did they act together? Although not so conspicuous, the ambiguity is a real one, since the sentence in (45a) might be intended to refer to those tubes that were moved one by one by certain cranes acting collectively, rather than to some other tubes that were moved in a different way.

The restrictor of a natural language quantifier can have a complex structure not only due to the presence of head noun modifiers, but also due to the occurrence of conjunctions as in (46).

[7] See Ruys and Winter, 2011, who discuss many other subtleties concerning scope restrictions in English, and Szabolcsi, 2010 who also considers scope phenomena in other languages.

Conjunctions in combination with adjectives and other modifiers moreover give rise to questions of scope, as illustrated by the bracketings in the example sentences with conjunctions and adjectives in NP heads in (46).

(46) a. (More than two thousand) (men and women) signed the petition.

b. (More than fifty) (ancient (books and manuscripts)) were rescued.

c. (More than fifty) (ancient (books) and (film scripts)) were rescued.

d. (More than fifty) (ancient (books, manuscripts and paintings)) were rescued.

e. (More than fifty) (ancient (books), magazines and photo albums) were rescued.

f. (More than fifty) (valuable (ancient (books and manuscripts))) were rescued.

g. (More than fifty) (valuable (ancient (books) and paintings)) were rescued.

h. Some (beautiful (old (photographs)) and (valuable (ancient (books) and paintings)) were rescued.

Similar scope ambiguities as for adjectives arise for other forms of head modification, such *as "Arts and crafts museum", "Men and women from Nigeria", "Books and paintings that were rescued",* and so on.

2.8 Mass terms and quantification

Most studies of quantification in natural language have been restricted to cases where the NP head is a 'count noun', i.e. a noun that has both a singular and a plural form, and that can be combined with numbers, as in *"three men"* and *"two pianos".* In contrast with count nouns, mass nouns, such *"water", "gold", "music", "poetry",* and "*furniture*" have only one form (usually singular) and cannot be quantified by means of numbers; instead, they require 'amount expressions' (also called 'measure phrases') for making a quantified predication, as illustrated in (47):

(47) In constructing the new platform, more than five hundred tons of concrete was used.

Universal quantification with a mass noun, as in "all the beer", is syntactically very similar to the count noun case, but semantically different; compare the two sentences in (48):

(48) a. The boys ate all the apples in the basket.

b. The boys drank all the beer in the fridge.

In (48a) a predicate is applied to a set of apples, and likewise in (48b) a predicate is applied to a set of quantities of beer. A difference is that (48a) can be analysed as: "Every one of the apples in the basket was the object in an eat-event with one of the boys as the agent", but it is not clear that the analogous analysis "Every quantity of beer in the fridge was the object in a drink-event with one of the boys as the agent" would make sense, since the set of quantities of beer in the fridge does not just consist of the bottles of beer that were there, but also of smaller quantities that can be taken from a bottle, like glasses and sips. A universal mass noun quantification of the form *"all the M"* does not necessarily refer to *all* the contextually relevant quantities of M, but rather to a certain subset of quantities that has the property of together making up the whole of "the M". (This situation may arise also for count NPs in case the individuals in the quantification domain have an internal part-whole structure, as in *"The boys ate all the pizzas"*.)

Count/mass is not a distinction between words, but between different ways of using words, as illustrated by the following pairs of sentences: "There's no chicken in the yard"/"There's no chicken in the stew" and *"Can I have some coffee?"/"Can I have two coffees?"* (see further Bunt, 1985).

A detailed analysis of quantification in relation to mass terms can be found in Bunt (1985), who analyses the notion 'quantity of' as a part-whole relation, defining a join operation Σ (a.k.a. 'sum') on quantities such that two quantities of M joined together form another quantity of M (similar to the operator used in (17) for joining parts of an individual.) An expression of the form *"all the M"* with a mass noun *"M"*, can be interpreted as referring to a set X of quantities of the reference domain M_0 that together make up the whole of all M_0, i.e. whose join equals the join of all quantities of M_0: $\Sigma(X) = \Sigma(M_0)$).

Quantification by means of mass NPs is, like quantification with count NPs, characterized by a distribution, scope, definiteness, domain involvement, and size of the reference domain or of parts of it, but there are some notable differences in distribution and in the expression of involvement and size.

Since mass nouns do not individuate their reference, quantification by mass NPs would seem not to allow individual distribution. Yet there is a distinction somewhat similar to the individual/collective distinction of count NP quantifiers, as (49) illustrates.

(49) a. All the water in these lakes is polluted.

b. The sand in the truck weighs twelve tons.

c. The boys carried all the sand to the back yard.

d. The crane lifted all the sand.

In (49a) the predicate of being polluted applies to any sample of *"the water in the lake";* this distribution is called 'homogeneous'. In (49b) the predicate of weighing 12 tons applies to the quantities of sand taken together, so this is a form of collective quantification. In (49c) the boys did not carry *every* quantity of sand, but certain quantities that together make up *"all the sand",* similar to (48b) above; in this case the distribution is called 'unspecific'. Sentence (49d) can be considered to be ambiguous between a collective and an unspecific reading.

Expressions of proportional involvement, like *"some pasta", "most of the pasta", "all the pasta"* cannot be interpreted in terms of numbers of quantities. As the examples in (48b) and (49) illustrate, complete involvement of a mass NP reference domain means that the merge of the quantities involved forms the entire domain. Non-zero involvement means that al least one quantity of non-zero size is involved, and "*most M*" quantification over reference domain M_0 means that $|\Sigma^+(X)| > |\Sigma^+(M_0)|/2$, where '| |' indicates size.[8] Size measurement is discussed below.

The examples in (48b) and (49) illustrate three different ways in which the quantification domain of a mass NP can be completely involved in a predication, corresponding to three different senses of expressions of the form "*all M"* (or *"all the M*") in English, and similarly in other languages. Complete involvement with homogeneous distribution, as in (49a), where "*all the water*" refers to the set of all

[8] If P is a one-place predicate, the notation |P| will also be used to designate the cardinality of the set that P is the characteristic function of (i.e. the set of all and only those elements that have the property P). Similarly, if Q is another such predicate, then $|P \cup Q|$ designates the number of objects that either have the property P or the property Q (or both).

contextually distinguished quantities of water, will be indicated in annotations by the 'involvement' attribute having the value "all". In cases like (48b) and (49c), where "*all the sand*" refers to a subset of quantities of sand that together make up all the (contextually distinguished) sand – the 'involvement' attribute has the value "total". Finally, on the collective reading of (49b, d), where "(*all) the sand*" refers to the quantity of sand formed by all contextually relevant quantities of sand together, the involvement will be annotated the same as in the case of collective count NP quantification, viz. as "all". This is summarized in Table 1.

involvement	*distribution*	*interpretation*	*example*
all	homogeneous	For all quantities of M	(49a)
total	unspecific	For the elements in a set of quantities of M that together make up the whole of M	(48b), (49c)
whole	collective	For M as a whole	(49b)

Table 1. Involvement and distributivity in mass NP quantification.

The relative scoping of a mass NP quantifier and a count NP quantifier, or of two mass NP quantifiers, is no different from that of two count NP quantifiers, as illustrated by (50):

(50) a. Everyone should read three papers.

b. Everyone should study 500 lines of poetry.

Since mass noun denotations are uncountable, the absolute quantitative involvement and the size of a quantification domain are measured in terms of numbers of units in some dimension, such as volume or length. Duration, length, volume, weight, price and many other ways of measuring 'amounts' of something are linguistically expressed by means of a unit of measurement plus a numerical indication, such as "*one and a half hours*", "*90 minutes*", "*just over two kilos*". From a semantic point of view, a measure is an equivalence class formed by pairs <*n,u*> where *n* is a numerical predicate and *u* is a unit. Given the relations between the units in a particular system of units, any of the equivalent pairs can serve as a representative of the equivalence class. For instance, <*1.5, hour*> represents the same amount of time as <*90, minute*>; they belong to the same equivalence class since 1 h = 60 min.

Units can be complex, like 'kilowatt-hour' (unit of electrical energy) or 'meter/second' (unit of velocity). Formally, a unit is either a basic unit or a triple

(51) $<u_1, u_2, Q>$

where $Q = \times$ (multiplication) or $Q = /$ (division) and u_1 and u_2 are (possibly complex) units. This allows for complex units such as *meter/(second × second)* (meter per square second) for measuring acceleration, and *euro/(meter × meter)* for measuring the price of land. ISO 24617-7 Spatial information (ISO-Space) includes amounts (called 'measures') of space for measuring distances; ISO 24617-1 Time and events (ISO-TimeML) includes amounts of time for measuring durations. In both cases, only elementary units are considered, which is too limited for dealing with velocities, accelerations, etc.

Amount expressions can be used not only to specify an involvement or a size in the case of a mass noun quantification, but also for doing so in the case of a count noun quantification, as illustrated in *"Five kilos of apples."* For more details about the analysis and annotation of amount expressions see ISO 24617-6.

The abstract syntax of annotations for quantities can be defined by introducing pairs *<n,u>,* where *'u'* is either an elementary unit or a triple, as indicated above in (51). A corresponding XML-based concrete syntax uses an element 'amount' with attribute - value pairs for the numerical part and the unit part, as in (52) (where markable m1 refers to "*three miles*").

(52) a. three miles
b. <amount xml:id="am1" target="#m1" num="3" unit="mile"/>

3 QuantML

3.1 Overview

This section specifies the QuantML markup language. From a syntactic point of view, QuantML is just a compact form of XML; its importance is that it defines a class of XML expressions that have a formal semantics. Following the methodological ISO standard 24617-6 (Principles of semantic annotation), this specification consists of four parts:

1. A metamodel, providing a schematic overview of the concepts that may occur in annotations, and the relations between them.
2. An abstract syntax, providing a formal specification of the inventory of the concepts from which annotations are built up and of the possible ways of combining them, using set-theoretical operations, to form conceptual structures called 'annotation structures'.
3. A concrete syntax, defining a representation format for annotation structures.
4. A semantics, defining an interpretation of annotation structures (and their representations).

The abstract syntax of an annotation scheme specifies the information in annotations in terms of set-theoretical structures such as pairs and triples. A concrete syntax specifies a representation format for annotation structures, such as the XML format used in (17) and (20), where a triple like $<e_1, e_2, R_i>$ is represented by a sequence of XML elements, of which the element <srLink event="#e1" participant="#x1" semRole="agent"/> represents the relation and the other two elements represent two entity structures.

A representation format for annotation structures should ideally give an exact expression of the information contained in annotation structures. A concrete syntax, defining a representation format for a given abstract syntax, is said to be *ideal* if it has the following properties:

— **completeness**: every annotation structure defined by the abstract syntax can be represented by an expression defined by the concrete syntax;

— **unambiguity**: every representation defined by the concrete syntax is the rendering of exactly one annotation structure defined by the abstract syntax.

The representation format defined by an ideal concrete syntax is called an *ideal representation format*. Any two ideal representation formats are semantically equivalent, in the sense that representations in one format can be converted to the other in a meaning-preserving way (namely, both representations have the meaning of the annotation structure that they represent).

3.2 Metamodel

A metamodel gives a schematic overview of the abstract syntax of a class of annotations, typically slightly simplified. It shows the concepts that go into annotations and indicates how they are related. The metamodel in Fig. 1 is simplified in that it does not show the internal structure of some of the concepts, such as the different possible ways of modifying an NP head, or the internal structure of domain sizes and frequencies.

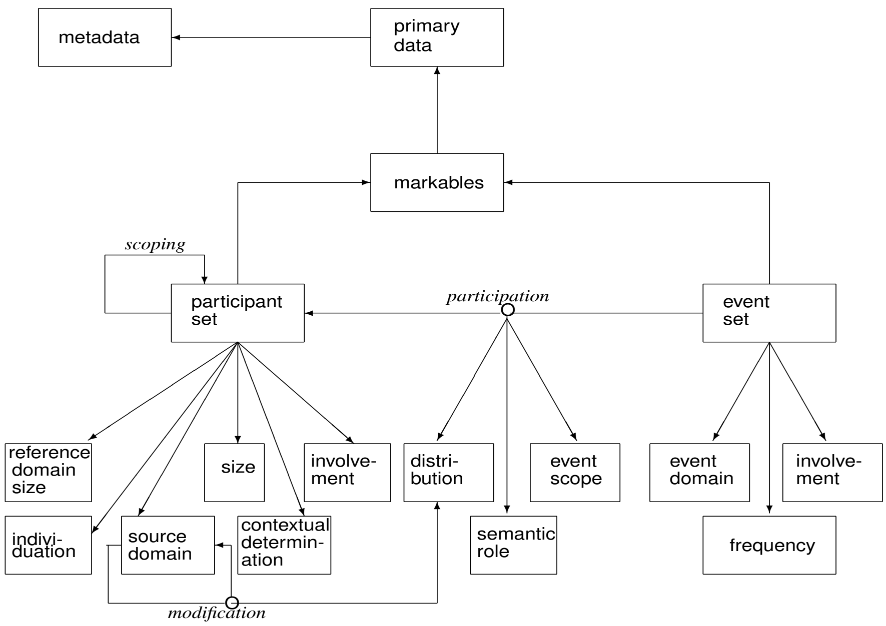


Figure 1: Metamodel for the annotation of quantification

According to the analysis of quantification given in Section 6, the set of participants in a quantified predication is characterized by the following properties:

1. the *source domain* from which the participants in a certain set of events are drawn (actual participants being elements, collections of elements, or parts of the source domain);
2. the *event domain* to which the eventualities belong in which the participants are involved;
3. the determination, through contextual information and/or central determiners (the definiteness of an NP) of the *reference domain* of the quantification (i.e. a subset or part of the source domain, possibly the entire source domain);

4. the way in which elements or parts of the reference domain participate in a set of events: the individuation of the reference domain (individual objects, possibly also their parts, or quantities of masses), the *distribution* of the quantification, the semantic role, and the relative scope of the quantified relation over events and participants;
5. the quantitative (absolute or proportional) *involvement* of the reference domain;
6. the size of the reference domain, or of groups, subsets, or parts of the reference domain involved in the quantifying predication;
7. the size of the set of events in the quantification and the frequency of repetitive events.

The metamodel also shows that the events and their participants in a quantification are linguistically expressed: they are related to a markable, which identifies a region of primary data. By contrast, the participation relation (and its semantic role) and relative scope relations are not verbalized, and hence do not relate to markables. Some of the other properties are mostly verbalized, such as size and frequency; others are sometimes verbalized but may be implicit (definiteness, involvement); this is not shown in the metamodel, in order not to clutter it up. Similarly, the metamodel does not show that an event set may have a frequency or a size, but not both.

3.3 Abstract syntax

3.3.1 Overview

The structures defined by the abstract syntax are *n*-tuples of elements that are either basic concepts, taken from a store of basic concepts called the 'conceptual inventory', or *n*-tuples of such structures. Two kinds of structures are distinguished: *entity structures* and *link structures.* An entity structure contains semantic information about a segment of primary data and is formally a pair $<m, s>$ consisting of a markable, which refers to a segment of primary data, and certain semantic information. A link structure contains information about the way two or more segments of primary data are semantically related; for example, in semantic role annotation a link structure is a triple $<e_1, e_2, R_i>$ where e_1 is an entity structure that contains information about an event, e_2 is an entity structure that contains information about a participant in the event, and R_i is a relation denoting a semantic role.

According to the analysis of quantification, reflected in the metamodel, of central importance are sets of events, sets of entities participating in events, and the semantic relation between them. The first two of these correspond to entity structures, while the latter corresponds to a link structure.

3.3.2 Entity structures for events and participants

Of the properties that characterize a set of participants involved in a quantification, the source domain, the involvement of the reference domain, and the definiteness of the reference domain must be specified in order for the quantification to be semantically interpretable; these elements are thus obligatory in the annotation of a quantification. The entity structure $<m, s>$ for a set of participants thus contains minimally a triple:

(53) $\varepsilon_p = <m, <S, q, d>>$

with S = source domain specification, q = reference domain involvement, and d = definiteness. Such triples correspond to NPs that do not contain cardinal determiners or amount qualifiers.

Cardinal determiners, as already adumbrated in Section 6.2, can indicate the involvement of the reference domain, the size of the reference domain, or the size of groups, subsets or parts of the reference domain. The same is true for amount expressions as determiners in mass NPs.

The function of a cardinal determiner or amount qualifier depends on its syntactic position. Of the three positions in a determiner sequence (pre-determiner, central determiner, post-determiner), cardinal determiners can occur only in post-determiner position and in pre-determiner position in a partitive construction, such as *"Two of my sons"* and "*Five hundred grammes of this pasta*" in English, and *"Un de mes amis"* in French. In pre-determiner position, a cardinal determiner expresses domain involvement (as in *"Fifteen of these students read two papers*), or group size (as in *"Two of my sons carried a piano upstairs",* in a situation where one pair of sons carried one piano, another pair another piano, and a third pair a third piano), or the size of reference domain subsets whose members participate individually within the scope of another quantifier, as in *"Every student has to read three papers",* on the reading with individual distribution over papers and wide scope of *"Every student"* (so that each student is associated with a possibly different subset of three papers). In post-determiner position, a cardinal determiner always indicates the size of the reference domain (as in *"two of my three sons"*).

In addition to the three elements mentioned in (53), a participant entity structure may thus contain a fourth component that specifies a reference domain size or the size of subsets of participants, depending on the distribution and the relative scoping of participants. In sum, the semantic information in participant entity structures may be a triple <source domain, involvement, definiteness>, or a quadruple <source domain, involvement, definiteness, size>.

A participant entity structure is thus one of the structures in (54):

(54) $\varepsilon_p = \langle m, \langle S, q, d\rangle\rangle$ or $= \langle m, \langle S, q, d, N\rangle\rangle$.

Of these three or four components, the source domain specification (S) may have a complex internal structure, which is considered in Section 3.3.4. In exceptional cases, such as the examples in (10), the restrictor part of the NP is empty, and the source domain is implicit.

The components q and N in a participant entity structure are a quantitative predicate, such as $\lambda z.\ |z| > 5$, possibly involving an amount specification, such as $\lambda z.\ |z| > (5, \text{kilo})$. The component q ('involvement') may additionally also be a proportional predicate, such as $\lambda z.\ |z| = |P_1|$ (corresponding to "All P1"), also indicated as 'all' (and $\lambda z.\ |z| > 0$ is also indicated by 'some'). For a mass NP quantifier the components q and N are slightly different from when the NP concerns a countable domain, therefore the specification of the source domain in (54) is a pair S = <D,v> where v indicates the individuation of the domain (v = 'count', or v = 'mass', or v = 'count/parts' if parts of individuals are considered).

Component d (definiteness) is an unstructured value, viz. 'definite' or 'indefinite'.

Participant entity structures corresponding to sets of individuals, a limiting case is that of a set of just one individual. In GQT, proper names like "Santa" or "Donald Duck" are viewed as quantifiers concerning sets that contain one specific member, the named individual. This applies even to a common proper name like “John Smith”, although there are many people with that name: whenever a proper name is used, the speaker has a particular individual in mind, who is not unique in an absolute sense, but who is uniquely determined for the speaker and his interlocutors in the given context by his salience, familiarity, or recent mention. Entity structures for such cases have a reference domain consisting of a single individual.

Entity structures <m, ε_{EV}> for sets of events are simpler than those for sets of participants; they contain besides a markable a predicate that characterizes a domain of events, and possibly in addition either (a) the cardinality of a set of repeated events or (b) the frequency of repeated events:

(55) ε_{EV} = <m,event domain> or <m,<event domain,event domain size>> or
<m,<event domain,frequency>>

An “event domain” is a class of events, analogous to the source domain of a set of participants; “domain size” is analogous to “reference domain size” and is relevant for the analysis of iterated events, as in “*John called more than once”,* and ‘frequency’ is for expressing the number of repeated events over a certain length of time, as in “*Call me every two hours”.* The size of an event domain is a numerical predicate, such as $\lambda x.\ |x|=2$ (abbreviated “2”) or $\lambda x.\ |x|>1$ (“>1”); a frequency is a pair consisting of a numerical predicate and a length of time. Additional entity structures are defined below (7.3.4) for the expression of NP head noun modification.

3.3.3 Link structures

The abstract syntax defines link structures for participation in an event and for the relative scoping of participants. *Participation structures* (56a) connect participants to events with a semantic role, the distribution of the relation, and whether the quantification over events has wide or narrow scope. Collective distribution means that a set of individuals is participating as a whole, acting as a single participant; in that case the quantification is scopeless, hence the link structure is just a quadruple. *Scope link structures* (56b) indicate a scope relation between two participant entity structures.

(56) a. L_P = < ε_p, ε_{EV}, semantic role, distribution, scope relation> or
< ε_p, ε_{EV}, semantic role, collective distribution>
b. L_{SC} = < ε_{p1}, ε_{p2}, scope relation>

3.3.4 Structured quantification domains

Of the components of a participant entity structure, the source domain associated with a quantified NP requires a structured specification when the restrictor contains one or more head noun modifiers and/or multiple, conjoined heads, as illustrated by the examples in (47). The abstract syntax supports articulate annotation of structured quantification domains by allowing the source domain to be either a single unmodified domain or a pair <<D_1, D_2, … D_k>, modifiers> consisting of a non-empty sequence of subdomains, corresponding to the members of a conjunction of heads, and a (possibly empty) sequence of modifiers that apply to (all) the members of this conjunction. In view of the possible complexity of conjunctive modified NP heads, a subdomain D_i may again be a conjunction and may again be modified, as illustrated by “*valuable (ancient (books) and paintings)”* in (47h). The specification of the restrictor part of an NP therefore makes use of recursive and non-recursive 'domain specification structures', the latter for the simple case of a (sub-)domain formed by the denotation of a single head noun possibly with one or more restrictive modifiers.

The analysis of distribution and scope of NP head noun modifiers in sub-section 6.6 leads to the conclusion that four types of modification can be distinguished, as summarized in Table 2:

1) with individual (count) or homogeneous (mass) distribution and non-inverse linking;
2) with individual (count) or homogeneous (mass) distribution and inverse linking;
3) with collective distribution (count or mass) and without inverse linking;
4) with unspecific distribution (count or mass) and without inverse linking.

For annotating NP head modifications, adjectives and modifier nouns do not need to specify the linking, since this is never inverse, whereas PPs and relative clauses do need this.

NP head noun	*distribution*	*link inversion*	*modifier category*
count mass	individual homogeneous	no	ADJ, NN, PP, RC
count mass	individual homogeneous	yes	PP, RC
count, mass	collective	no	ADJ, PP, RC
count, mass	unspecific	no	RC, PP

Table 2. Types of NP head modification.

Noun-noun (NN) modification of a count noun always has individual distribution, and of a mass noun always has homogeneous distribution, so the distribution in a NN-modification does not need to be annotated. If the modifier is a bare noun, the linguistic information in the modification is a property that characterizes a certain concept. However, the modifying noun may itself by modified by an adjective, as in *"chemical waste dump"* (to be contrasted with *"old waste dump"*), or *"natural language processing"*, in which case the modification is a structured property.

So in general the modifying information consists of the property expressed by the noun, combined with the semantic information in any restrictions that may modify the noun. Inverse linking does not arise in adjectival modification, therefore an entity structure for a modifying noun in NN-modification is a pair consisting of a unary predicate constant and a (possibly empty) set of (adjectival or NN) restrictions:

(57) ε_{NN} = <markable, <property, restrictions>>.

An adjective can be used not only for modifying an NP head noun, but also for modifying a noun that modifies another noun, This phenomenon is treated in this document as introducing a complex concept, such as ‘ toxic waste’ or ‘natural language’. An entity structure for adjectival modification is therefore a pair consisting of a unary predicate constant and a distributivity:

(58) ε_{AD} = <markable, <property, distributivity>>.

Adverbial modification of adjectives (e.g. *“very beautiful”, “too expensive”, “most reliable*”, *“more expensive than expected*”,…} } is considered to be outside the scope of the standard specified in this document.

In PP modification, the semantic information about the PP consists of the relation expressed by the preposition and the information about the embedded NP, as described by a participant structure ε_P. For modification by a PP both the distributivity is relevant and the scoping (inverse linking or not – the latter case will be called ‘*linear’* linking). Hence an entity structure for PP modification contains a quadruple:

(59) ε_{PP} = <markable, <relation, ε_P (participant structure), distributivity, linking>>.

In modification by a relative clause, the semantic information to be captured in annotations consists of the specification of the events with their participants as described in the (relative) clause, the annotation of which is through an annotation structure, plus the semantic role that the participants indicated by the head play in the RC’s set of events, the distributivity of the modification, and whether inverse linking occurs. The entity structure for a relative clause is thus:

(60) ε_{RC} = <markable, <annotation structure, semantic role, distributivity, linking>>.

For example, the participant entity structures (containing modifier link structures and recursively embedded entity structures) for the quantifications with structured domains corresponding to the underlined NPs in (37a,b,c), repeated here as (6!a-c), and in (61d-g) are as follows (for the collective reading of (61c)) - square brackets are used here to mark domain specification structures for increased readability:

3.3.5 Formal specification

As mentioned above, the abstract syntax of the proposed annotation of quantification consists of a ‘conceptual inventory', specifying the concepts from which annotations are built up, and a specification of the possible ways of combining these elements to form ‘annotation structures’.

Conceptual inventory The conceptual inventory specifies the ingredients of annotations according to the metamodel shown in Figure 1. These ingredients are the entities that populate the entity structures and link structures that form annotation structures. The QuantML conceptual inventory is specified below.

Annotation structures for quantification are associated with sentences and relative clauses; more generally with the units that in linguistics are called ‘clauses’, i.e. a finite verb and its arguments. It is at this level of syntactic structure that issues arise of the relative scopes of participants in different roles, as well as relative scopes of events and participants. Such annotation structures are quadruples, consisting of an event structure, a non-empty set of participant structures, a set of link structures that link participants and events, and a (possibly empty) set of scope link structures; see

(62), where ε_{EV} is an event structure; $\varepsilon_{P1},\ldots, \varepsilon_{Pn}$ are participant structures; $L_{P1},\ldots, L_{Pn}$ are participation link structures, and $sc_1,\ldots, sc_k$ are scope link structures (i.e. relations between participant structures).

(62) $\langle \varepsilon_{EV}, \{\varepsilon_{P1},\ldots, \varepsilon_{Pn}\}, \{L_{P1},\ldots, L_{Pn}\}, \{sc_1,\ldots, sc_k\}\rangle$

Entity structures:

Entity structures are pairs <m,s> consisting of a markable m and certain semantic information, designated here by 's'. For convenience, some auxiliary structures are used in the definition of the QuantML entity structures. The following types of entity structure are defined, with their respective structure of the latter component:

1. Participant structures: s = <DS, q, d> or s = <DS, q, d, N>, where DS is an auxiliary structure called a domain specification structure (see below), q is a specification of reference domain involvement, which is another auxiliary structure), d is a definiteness, and N is a size specification, again an auxiliary structure. If the reference domain consists of a single individual concept, as in the case of a proper name (e.g. "Santa") or a singular definite description ("the Christmas man", "the president"), then the domain involvement is redundant (and may e.g. be set to "all"), the definiteness is "definite", and the size specification is N = 1.
2. Event structures: s = <E> or s = <E, N> or s = <E, N, t> where E is a predicate denoting an event type, N is a numerical predicate, and t is a temporal unit.
3. Modifier structures:
   a. Adjectival structure: s = <property>;
   b. Modifying noun structure: s = <property> or <property, sequence of adjectival modifiers>;
   c. PP structure: s = <relation, participant structure,>;
   d. Relative clause structure: s = <semantic role, annotation structure>.

Auxiliary structures:

4. A domain specification structure is a pair DS = <S,v>, where v is an individuation specification and S is a domain structure, i.e. S is either a single domain name D, or a sequence of domain structures $\langle S_1, \ldots S_k\rangle$, or a pair <S, M> consisting of a domain specification structure and a sequence of one or more 'modification specifications' (see next item).
5. A modification specification is either a modifying noun structure, or a pair <adjectival structure, distribution>, or a triple <PP structure, distribution, linking>, or a triple <relative clause structure, distribution, linking>.
6. A specification of reference domain involvement indication is either a numerical predicate or an amount structure, i.e. a pair <n, u> consisting of a numerical predicate n and either a basic unit of measurement or a unit structure. A unit structure is a triple $\langle u_1, r, u_2\rangle$, where u_1 and u_2 are either a basic unit or a unit structure, and r is either the operation of multiplication or that of division.

Link structures: The following types of link structure are defined:

1. Participation links: <event structure, participant structure, semantic role, distribution, event scope, polarity>.
2. Scope relation links: < participant entity structure, participant entity structure, scope relation>.

The types of entities to be provided by the conceptual inventory follow from these entity and link structures:

1. predicates denoting source domains in domain specification structures; these concepts are designated by the corresponding lexical items of the language of the annotated primary data, such as ‘book’, ‘student’, and ‘water’;
2. predicates that characterize an event domain; lexical items from the language of the annotated data are used to designate these concepts, such as ‘lift’, ‘carry’, ‘read’, ‘see’, ‘meet’;
3. predicates corresponding to adjectives in adjectival restriction links (inside domain specification structures); lexical items from the language of the annotated data are used to designate these concepts, such as ‘Chinese’, ‘heavy’, and ‘rare’;
4. relations corresponding to prepositions in PP restriction links; prepositions from the language of the annotated data are used to designate such relations, such as ‘from’ and ‘in’;
5. semantic roles (in participation links and in relative clause links); for this purpose, the semantic roles defined in ISO 245617-4 (Semantic roles) are used;
6. numerical predicates to specify absolute reference domain involvement, reference domain size, or the size of certain parts of a reference domain, or the number of repetitions or frequency of recurrence in event structures; such predicates specify a number or a range of numbers; such as ‘5’ (formally: $\lambda x.\ card(x)=5$, also written $\lambda x.\ |x|=5$); “more than one”, and “between 1200 and 1400”; other numerical predicates vaguely specify a numerical value, such as “many”, “not much”, “several”, “a few”, “a couple”, “some”, and “a little”;
7. predicates for specifying proportional reference domain involvement (in participant structures), such as “all”, “a”, “some” (for count NPs), “most”, and for mass NPs: “total”, “all”, “whole”, “some-m”, and “most-m”;
8. parameters for specifying definiteness (in participant structures): “definite” and “indefinite”
9. basic units of measurement, such as ‘meter’, ‘kilogram’, ‘litre’, and ‘hour’ – see ISO 24617-6 (Principles of semantic annotation) and Hao et al. (2017); for measuring temporal length the units listed in ISO 24617-1 (ISO-TimeML) are used;
10. the operators ’division’ and ‘multiplication’ for forming complex units;
11. the values ‘positive’ and ‘negative’ for specifying a polarity;
12. parameters for specifying distribution: ‘collective’, ‘individual’, ‘homogeneous’, ‘group’, ‘unspecific’;
13. parameters for specifying individuation: ‘count’, ‘mass’, and ‘‘count’/parts’;
14. parameters for specifying event scope: ‘wide’ and ‘narrow’;
15. ordering relations for specifying relative scopes of sets of participants (in participant scope links): ‘wider’, ‘equal’, ‘dual’, and ‘unscoped’;
16. parameters for specifying whether scope inversion occurs (in PP modification): ‘inverse’ or ‘linear’ (default value).

3.4 Concrete syntax

3.4.1 XML Specification

A concrete syntax is specified here in the form of an XML representation of annotation structures. For each type of entity structure, defined by the abstract syntax, a corresponding XML element is defined; each of these elements has an attribute @xml:id whose value is a unique identification of (an occurrence of) the information in the element, and an attribute @target, whose value anchors the annotation in the primary data, having a markable as value (or a sequence of markables). In addition, these elements have the following attributes:

1. the XML element <entity>, for representing participant structures, has the attributes @domain, @involvement, @definiteness and (optionally) @size;
2. the XML element <event>, for representing event structures, has the attributes @pred for specifying an event type, @number (optional), and @frequency (optional);
3. the XML element <qDomain>, for representing domain specification structures: has the attributes @source (with multiple values in the case of a conjunctive specification) and @restrictions;
4. the XML element <sourceDomain>, for representing quantification source domain specifications without modifiers: has (beside @target) the attributes @pred and @individuation;
5. the XML element <adjMod>, for representing adjectival modifiers, with the attributes @pred and @distr, and optionally the attribute @restrictions;
6. the XML element <nnMod>, for representing nouns as modifiers, with the attributes @pred and @distr;
7. the XML element <ppMod>, for representing PP modifiers, with the attributes @pRel, @pEntity, @distr and @linking;
8. the XML element <relClause>, for representing relative clauses, with the attributes @semRole, @clause, @distr and @linking;
9. the XML element <amount> has the attributes @num, and @unit;
10. the XML element <complexUnit>, has the attributes @unti1, @operation, and @unit2.

For the two types of link structure defined by the abstract syntax, a corresponding XML element is defined:

1. <participation> has the attributes @event, @participant, @semRole, @distr, @evScope (default value: "narrow") and @polarity (default value: 'positive);

2. <scoping> has the attributes @arg1, @arg2, @scopeRel.

Note that the attributes defined in this concrete syntax come in three varieties as far as their kinds of values are concerned: (1) those whose values are entity structures or link structures, such as @domain, @event, and @restrictions; (2) those whose values correspond to concepts, denoted by natural language content words, such as @pred and @pRel (in PP restrictions); (3) those whose values correspond to linguistic concepts and parameters, specified in the conceptual inventory, that serve to make certain semantic linguistic distinctions, such as @definiteness, @distr, and @scopeRel.

For attributes of the second kind, notably for the @pred attribute, the values are provided by the nouns, verbs, adjectives and prepositions that constitute the corresponding markables in the annotated data. These values can be obtained by means of morphological preprocessing and lexical lookup (possibly with support for word sense disambiguation). In the example annotations in this document, such semantic values are represented by lexical items of the language of the primary data in the form of verb stems, singular (masculine) forms of nouns, and singular (masculine) forms of adjectives – the precise choice of these forms depends on the object language under consideration. For example, using ‘L_{L1}’ to designate a lookup function that delivers (disambiguated) lexical items in the desired form for the language ‘L1’, the values of the three occurrences of the @pred attribute in example (63) below are L_{EN}(m5) = “enroll”, L_{EN}(m3) = “student”, and L_{EN}(m2) = “chinese”, respectively; for better readability of the annotations these values are shown rather than “L_{EN}(m5)” etc. (Note that, for convenience, the same values are also used in the abstract syntax.)

For attributes of the third kind the values are largely but not entirely language-independent; this document only considers attribute values of general linguistic significance, which is not restricted to English or any other particular language.

3.4.2 Examples of annotation representations

(63) Thirty-two Chinese students enrolled.

Markables:

m1=Thirty-two Chinese students, m2=Chinese, m3=Chinese students, m4=students, m5=enrolled

QuantML Representation:

```
<entity xml:id=”x1” target=”#m1” domain=”#x2” involvement=”32” definiteness=”indef’”/>
<event xml:id=”e1” target=”#m5” pred=”enroll”/>
<qDomain xml:id=”x2” target=”#m3” source=”#x3” restrictions=”#r1”/>
<sourceDomain xml:id=”x3” target=”#m4” individuation=”’count’” pred=”student”/>
<adjMod xml:id=”r1” target=”#m2” distr=”individual” pred=”chinese”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
  evScope=”narrow”/>
```

(64) Alex owns some (valuable (ancient (Chinese books) and Japanese paintings)).

Markables:

m1=Alex, m2=owns, m3=some valuable ancient Chinese books and Japanese paintings, m4= valuable, m5=valuable ancient Chinese books and paintings, m6=ancient, m7-ancient Chinese books, m8=Chinese, m9=Chinese books, m10=books, m11=Japanese, m12=Japanese paintings, m13=paintings

QuantML Representation:

```
<entity xml:id=”x1” target=”#m1” domain=”#x1” involvement=”1” definiteness=”def’”/>
<sourceDomain xml:id=”x1” target=”#m1” individuation=”count” pred=”alex”/>
<event xml:id=”e1” target=”#m2” pred=”own”/>
<entity xml:id=”x2” target=”#m3” domain=”#x3” involvement=”some” definiteness=”indef’”/>
<qDomain xml:id=”x3” target=”#m5” source=”#x4 #x6” restrictions=”#r1”/>
<qDomain xml:id=”x4” target=”#m8” source=”x5” restrictions=”#r2 #r3”/>
<sourceDomain xml:id=”x5” target=”#m9” individuation=”count” pred=”book”/>
<qDomain xml:id=”x6” target=”#m11” source=”x7” restrictions=”#r4”/>
```

```
<sourceDomain xml:id="x7" target="#m12" individuation="count" pred="painting"/>
<adjMod xml:id="r1" target="#m4" distr="individual" pred="valuable"/>
<adjMod xml:id="r2" target="#m6" distr="individual" pred="ancient"/>
<adjMod xml:id="r3" target="#m7" distr="individual" pred="chinese"/>
<adjMod xml:id="r4" target="#m10" distr="individual" pred="japanese"/>
<participation event="#e1" participant="#x1" semRole="theme" distr="individual"
  evScope="narrow"/>
```

(65) The three men moved two pianos

Markables: m1=The three men, m2=men, m3=moved, m4=two pianos, m5=pianos

QuantML Representation:

```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="3" definiteness="def""/>
<sourceDomain xml:id="x2" target="#m2" individuation="count" pred="man"/>
<event xml:id="e1" target="#m3" pred="move"/>
<entity xml:id="x3" target="#m4" domain="#x4" involvement="2" definiteness="indef"
        pred="piano"/>
<sourceDomain xml:id="x4" target="#m5" individuation="count"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="collective"/>
<participation event="#e1" participant="#x2" semRole="theme" distr="individual"/>
```

3.5 Semantics

3.5.1 Overview

The annotations of quantification defined in this standard have a compositional semantic interpretation defined in terms of (possibly underspecified) DRSs, compositional in the sense that the interpretation of an annotation structure is defined by combining the interpretations of its component entity structures, and participation link structures, in a manner that is determined by scope relations.

The present sub-section gives a brief overview of the semantics; more details, examples, and a formal specification of the semantics are provided in Appendix C.

The semantics follows the approach of Generalized Quantifier Theory combined with neo-Davidsonian event-based semantics, treating natural language quantifiers as expressing properties of sets of participants involved in sets of events. For example, the sentence "More than five thousand students protested" is interpreted as saying that there is a set X with the property of containing more than 5.000 students and a non-empty set of protest events in which the students in X were involved. A noun phrase of the form "More than five thousand P" is thus interpreted as a DRS of the form (66a), where capital letters are used to designate non-empty sets of individuals, and small letters to indicate individuals. This DRS says that there is a set X containing more than five thousand elements that all satisfy the predicate P.

(66a)

X
$\|X\| > 5.000$ $x \in X \rightarrow$ [| P(x)]

A definite NP is interpreted as expressing that there is a reference domain with the properties mentioned in the NP, which is determined by the context of utterance. Using, as before, the notation ‘P_0‘ to designate the predicate P restricted to the reference domain, this interpretation looks in DRS-form as shown in (66b) for an NP of the form “The three P”.

(66b)

X
$\|X\| = 3$
$x \in X \leftrightarrow P_0(x)$

For the sake of compactness, the notation $x \in A \rightarrow K$ (where K is a DRS) is used in this document as short for the usual box notation of DRT, with an implication relation between two sub-DRSs, and if K is a DRS of the form in (66a) also the notation $x \in A \rightarrow P(x)$ will be used.

Entity structures for noun phrases consisting of a proper name are interpreted as introducing a set that contains one individual. For example, the DRS in (67a) interprets the proper name “John Smith” as the singleton set containing the contextually identified individual who satisfies the condition $johnsmith_0(x)$.

(67a)

X
$\|johnsmith_0\| = 1$
$x \in X \leftrightarrow johnsmith_0 (x)$

To simplify notations, the occurrence of a DRS of the form (67a) in an embedded or embedding DRS will be abbreviated by using the name of the individual instead of the discourse referent, so for example, the clause “Annette called twice” will be represented as in (67b):

(67b)

E
$\|E\| = 2$
$e \in E \rightarrow$ [| call(e), agent(e,annette)]

Verbs are interpreted in the same way, except that their reference domain consists of events. For example, for the sentence “Annette called twice” the DRS interpreting “called twice” would be (67c):

(67c)

E
$\|E\| = 2$
$e \in E \rightarrow call(e)$

Structures like (66) and (67) are compositionally combined with structures like (68) in the semantics of participation link structures, as described below.

Following the principles of semantic annotation laid down in ISO 24617-6 (Principles of semantic annotation), the meaning of a quantification annotation is specified for the annotation structures defined by the abstract syntax and is inherited by the annotation representations in a format specified by a corresponding concrete syntax. More specifically, a recursively defined interpretation function I_A computes a DRS for each well-formed annotation structure. The interpretation of the entity and link structures includes the interpretation of their constituent elements from the conceptual inventory of the abstract syntax, in particular of the predicates that correspond to the denotations of nouns, verbs, adjectives, and prepositions. Following the notational conventions of Discourse Representation Theory, these predicates will be represented in DRSs by means of lexical items corresponding to nouns, verbs, adjectives, and prepositions of the language of the primary data.

3.5.2 Link structures without scope restrictions

For the annotation of a single quantification, formed by a set of events and a single set of participants, as in (69a), the annotation structure consists of two entity structures (an event structure and a participant structure) one link structure that relates the two, and an empty set of scope link structures.

(69) a. More than two thousand students protested

b. $\alpha = \langle \varepsilon_E, \{\varepsilon_{P1}\}, \{L_{P1}\}, \{\}\rangle$

The link structure L_{P1} has the form shown in (70), where the first two components are the linked event and participant structures, respectively, the third a semantic role, the fourth a distribution, the fifth a specification of whether the event structure has wider scope or narrower scope than the participant structure, and the sixth a polarity specification which, unless explicitly specified otherwise, is 'positive':

(70) $L_{P1} = \langle \varepsilon_E, \varepsilon_P, R, d, \sigma, p\rangle$

The interpretation function for such a structure is defined as follows:

(71) $I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, \sigma \rangle) = I_Q(\varepsilon_P) \cup (I_Q(\varepsilon_E) \cup I_Q (R, d, \sigma, p))$

The interpretation of quadruples <R, d, σ, p> and triples <R, collective, p> is a DRS that introduces discourse markers for non-empty sets of events and participants and the relation between them. For example, if the semantic role is Agent, the distribution is individual, the event scope is narrow, and the polarity is positive then the interpretation is the DRS in (72a), which says that there are sets of events and participants such that every participant is an agent in one of the events:

(72a) I_Q(Agent,individual,narrow, pos)=

E X
x ∈ X → [e | e ∈ E, agent(e,x)]

If the polarity is negative, everything else being equal, then the semantic interpretation is:

(72b) I_Q(Agent,individual,narrow, neg)=

X
x ∈ X → ¬ [e | e ∈ E, agent(e,x)]

If the event scope is 'wide', then the semantic interpretation is that there is a set of events and a set of participants such that for each of the events one of the participants is the agent:

(72c) I_Q(Agent,individual,wide, pos) =

<table><tr><td>E X</td></tr><tr><td>e ∈ E → <table><tr><td>x</td></tr><tr><td>x ∈ X
agent(e,x)</td></tr></table></td></tr></table>

For a scopeless link structure with collective distribution:

(73) I_Q(Agent,collective,pos) =

<table><tr><td>E X</td></tr><tr><td>e ∈ E → <table><tr><td>x</td></tr><tr><td>agent*(e,X)</td></tr></table></td></tr></table>

Merging the participation structure in (72a) with the DRSs (74), interpreting the participant structure and the one for the event structure (75), results in the interpretation (76) for the sentence (69a):

(74) $I_Q(\varepsilon_P)$ =

<table><tr><td>X</td></tr><tr><td>|X| > 2000
x ∈ X → <table><tr><td></td></tr><tr><td>student(x)</td></tr></table></td></tr></table>

(75) $(I_Q(\varepsilon_E)$ =

<table><tr><td>E</td></tr><tr><td>e ∈ E → <table><tr><td></td></tr><tr><td>protest(e)</td></tr></table></td></tr></table>

(76)

<table><tr><td>E X</td></tr><tr><td>|X| > 2000
e ∈ E → protest(e)
x ∈ X → <table><tr><td>e</td></tr><tr><td>e ∈ E
student(x)
agent(e,x)</td></tr></table></td></tr></table>

Note that the link structure in (70) embeds the event structure as well as the participant structure – annotations as defined by the abstract syntax are highly nested structures (as opposed to their 'flat' XML-representations). Therefore, the interpretation of the link structure provides the interpretation of the entire annotation structure. This is always the case for a well-formed and complete annotation structure, where all the participants are linked to certain events.

3.5.3 Interpretation of scope relations

The above example illustrates the interpretation of the simplest form of quantification, with a single quantifier, where scope issues do not arise. Only in that case is the interpretation of the sentence obtained by simply merging the interpretations of the annotations of its components.

When two or more sets of participants are involved in a set of events, the relative scoping of the quantifications over the sets of participants can be specified by scope link structures. This is illustrated by the interpretation of (78) for the wide-scope reading of “Fifteen students”:

(78) Fifteen students read three papers.

Markables: m1=Fifteen students, m2=students, m3=read, m4=three papers, m5=papers

Annotation structure:

< <m3, read>, {<m1, <<{<m2,student>, 15, indef>, <m4, <<<m5,paper>>, 3, indef>},
{<<m3, read>, <m1, <<{<m2,student>, 15, indef>, agent, individual, narrow>,
<<m3, read>, <m4, <<{<m5,paper>, 3, indef>, theme, individual, narrow},
{<<m1, <<{<m2,student>, 15, indef>, <m4, <<{<m5,paper>, 3, indef>}, wider>} >

XML Representation:

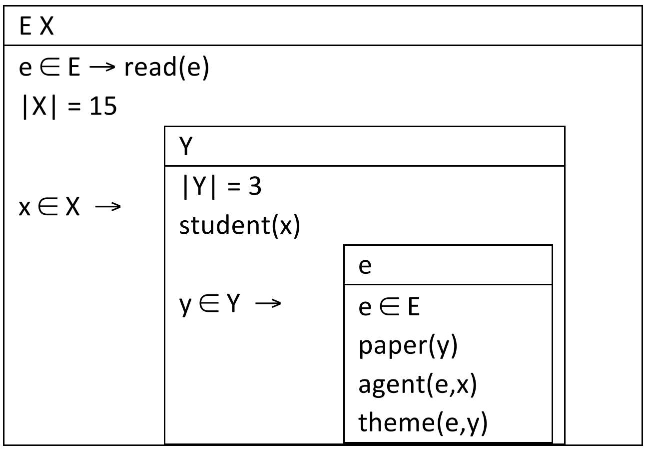
```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="15" definiteness="indef""/>
<sourceDomain xml:id="x2" target="#m2" pred="student"/>
<event xml:id="e1" target="#m3" pred="read"/>
<entity xml:id="x3" target="#m4" domain="#x4" involvement="3" definiteness="indef"/>
<sourceDomain xml:id="x4" target="#m5" pred="paper"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="individual"
   evScope="narrow"/>
<participation event="#e1" participant="#x3" semRole="theme" distr="individual"
   evScope="narrow"/>
<scoping arg1="#x1" arg2="#x2" scopeRel="wide"/>
```

The interpretation of the annotation structure is obtained by the ‘scoped merge’, explained below, of the DRSs that interpret the participation link structures as specified by clause (79) below, where $L_{E,P1}$ and $L_{E,P2}$ designate the two participation link structures, $<\varepsilon_{P1},\varepsilon_{P2},wide>$ designates the scope relation structure, and $\cup^s$ is the ‘scoped merge’ operation.

(79) $I_Q(<\varepsilon_E, \{\varepsilon_{P1},\varepsilon_{P2},\}, \{L_{E,P1}, L_{E,P2}\}, <\varepsilon_{P1},\varepsilon_{P2},wide>\}>) = I_Q(L_{E,P1}) \cup^s I_Q(L_{E,P2})$.

Application of this clause gives the result (80):

(80)



The ‘scoped merge’ operation is applicable to two arguments that both have the same form (81), where $C_1(X)$, $C_2(E)$ $C_3(Y)$ and $C_4(E')$ are sets of conditions on X and E, and on Y and E’, respectively, and K_1 and K_2 are sub-DRSs.

(81a)

X E
$C_1(X)$, $C_2(E)$ $x \in X \rightarrow K_1$

(81b)

Y E'
$C_3(Y)$, $C_4(E')$ $y \in Y \rightarrow K_2$

Given the arguments (81a) and (81b), the scoped merge of the first and the second argument, in this order, is defined as follows. Of the two pairs of discourse referents, one member of each pair is unified with a member of the other, e.g. E and E'. The corresponding conditions are also unified, The DRS of the second argument, with the discourse referent E' and the conditions $C_4(E')$ moved out, is merged with the sub-DRS D_1 of the first argument, with the result (82).

(82)

<table>
<tr><td colspan="2">E X</td></tr>
<tr><td colspan="2">$C_1(X)$
$C_2(E) \cup C_4(E)$</td></tr>
<tr><td>$x \in X \rightarrow$</td><td><table><tr><td>Y</td></tr><tr><td>$C_3(Y)$
$y \in Y \rightarrow K_1 \cup K_2$</td></tr></table></td></tr>
</table>

The scoped merge, symbolized by $\cup^s$, roughly speaking embeds the second argument in the first, reflecting that the first argument has wider scope than the second. The scoped merge operation may also be defined for two arguments that have only one discourse referent (or multiple discourse referents, rather than the single sets designated by X and Y in (81)). In that case the arguments and their scoped merge look as follows:

(83a) DRS_1=

X
C_1 $x \in X \rightarrow K_1$

(83b) DRS_2=

Y
C_2 $y \in Y \rightarrow K_2$

(84) $DRS_1 \cup^s DRS_2$ =

X
C_1 $x \in X \rightarrow K_1 \cup DRS_2$

The operation may also be generalized for more than two arguments. For example, in the case of three arguments of the form (81), which would correspond to three NPs expressing the quantified sets of arguments of a ditransitive verb (such as "give"), when the first argument outscopes the second and the second outscopes the third, this leads to an interpretation structure like (85).

(85)

$$
\begin{array}{|l|}
\hline
E\ X \\
\hline
C_1(X),\ C_2(E) \cup C_4(E) \cup C_6(E) \\
\\
x \in X \rightarrow
\begin{array}{|l|}
\hline
Y \\
\hline
C_3(Y) \\
y \in Y \rightarrow
\begin{array}{|l|}
\hline
Z \\
\hline
C_5(Z) \\
z \in Z \rightarrow K_1 \cup K_2 \cup K_3 \\
\hline
\end{array} \\
\hline
\end{array} \\
\hline
\end{array}
$$

3.5.3 Interpretation of complete and incomplete annotation structures

The semantic interpretation of a complete annotation structure (at the level of a linguistic clause) is in general obtained by first computing the interpretations of the participation link structures; these interpretations relate a set of participants to a set of events in a certain semantic role, and are subsequently combined to ensure that the right sets of participants are related to the *same* events. Scope link structures determine whether and how this combination makes use of various forms of (simple and scoped) DRS-merging. For annotation structures that do not fully specify the relative scopes of all the sets of participants involved in the same events, the semantic interpretation takes the form of a set of labelled (sub-)DRSs that express the semantics of the participation link structures, plus the scope restrictions for their possible combination. Such an interpretation is known in Discourse Representation Theory as an 'underspecified DRS' (UDRS, Reyle, 1994). For example, for an annotation structure with three participant structures and participation links, but only one scope restriction the interpretation is as follows:

$I_Q(<\varepsilon_{EV}, \{\varepsilon_P, \varepsilon_{P2}, \varepsilon_{P3}\}, \{L_{E,P1}, L_{E,P2}, L_{E,P3}\}, \{<\varepsilon_{P1}, \varepsilon_{P2}, wider>\}>) =$

$< \{L_1: I_Q(L_{E,P1}),\ L_2: I_Q(L_{E,P2}), L_3: I_Q(L_{E,P3})\},\ \{L_2 > L_3,\}>$

Appendix C provides more details about the semantics of QuantML annotation structures, including the interpretation of annotations of structured quantification domains, cumulative and group quantification, parts of individuals and parts of mass objects, and various kinds of modifiers, including modifiers with inverse linking.

4 Remaining issues and loose ends

Some of the phenomena relating to quantification in natural language that are not considered in this document, or only in a superficial way, are the following

1. Possessives, as in *"Every man loves his mother"*.
2. Non-restrictive and non-intersective modifiers, as in *"Those bloody communists", "A fake Ming vase"*.
3. 'Negative-polarity NPs', like *"nobody"* and *"nothing".*
4. Generics, as in *"A swan takes a mate for life", Lions are dangerous"*.
5. Habituals, as in *"Carl always talks about politics", "Mary takes oatmeal for breakfast"*.
6. Reciprocals, as in *"The students supported each other"*.
7. Reflexives, as in *"Every man shaves himself"*.

The absence of a full treatment of these phenomena is due partly to the fact that their theoretical status has not been fully resolved. This is for example the case for generics and habituals; see Kamp

& Reyle, 1993, Section 3.7.4. Krifka et al. (1995) analyse generics in terms of a special default quantifier; others introduce a notion of 'normal' or 'prototypical' into the interpretation framework (e.g. Eckhardt, 2000). Other phenomena, such as the use of non-restrictive and non-intersective modifiers, are rather peripheral w.r.t. the main issues in quantification. As this document develops further into an ISO standard, treatments of some of the phenomena in this list may be included.

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Appendix A. Annotation Guidelines

Quantification in natural language occurs when a verb is combined with one or more sets of arguments. Linguistically speaking, the annotation of quantification is relevant at the level of clauses, i.e. expressions that contain a verb and its arguments, and the relevant units are verbs and noun phrases.

Using the QuantML concrete syntax specified in this document, verbs are annotated with <event> tags as defined in ISO 24617-1 (ISO-TimeML) without necessarily using all the attributes defined for this tag; for example, the tense of a verb is not of interest for the annotation of quantification.

Noun phrases are viewed as denoting properties (or families) of sets of entities that participate in events. This is also true of singular NPs, like "a present" in example (4) in this document. For proper names and other singular NPs this may seem unnecessarily cumbersome, but the consistent treatment of NPs as corresponding to sets of individuals with certain properties simplifies the process of constructing semantic interpretations of annotations in a systematic and compositional manner. NPs are annotated using the <entity> tag. To provide values for the various attributes of an <entity> element, the following guidelines may be helpful.

@domain: in the general case, assign to this attribute as value a variable that identifies a <qDomain> element (which in turn refers to a <sourceDomain> element, or to another <qDomain> element if the head contains nested modifiers):

```
<entity xml:id=… target=… domain="#x2" involvement=… definiteness=… size=…/>
<qDomain xml:id="x2" target=… source=… restrictions=…/>
```

However, if the annotated NP has a single bare noun as its head, without any modifiers, then assign to this attribute as value a variable that identifies a <sourceDomain> element:

```
<entity xml:id=… target=… domain="#x2" involvement=… definiteness=…/>
<sourceDomain xml:id="x2" target=… pred="[noun]"/>
```

For NPs that are (singular) proper names, the same construction should be used, as follows:

```
<entity xml:id=… target=… domain="#x2" involvement="all" definiteness="def" size="1"/>
<sourceDomain xml:id="x2" target=… pred="james"/>
```

@involvement: If the NP contains a (pre-)determiner, such as "all', "each", "every", "a", "no", "some", or "most", then a corresponding QuantML string should be used as the value of this attribute. For determinerless plural NPs, the value "a" may be used for count head nouns, the value "some" for plural head nouns, and the value "some-m" for mass nouns, e.g. *"Does Anne have children?" = "Does Anne have a child?"* and *"Do you have fresh pasta?" = "Do you have some fresh pasta?"* For universal quantification over a mass NP, the three cases distinguished in Table 1 in Section 6.7 should be marked up as having the involvement "every", "total", or "whole", respectively.[9] For a singular proper name definite description ("the Christmas man", "the president"), or possessive ("my mother", "John's birthday") the involvement should be specified as "all" (other values such as "1" or "a" would be logically equivalent, but it is recommended to always use "all" in such cases).

[9] The semantics of the three forms of universal mass NP quantification is discussed below in Section C2.1.

@definiteness: This attribute should be assigned the value “indef” unless there is evidence that the NP quantifies over a specific, contextually determined subset of the source domain defined by the NP head plus its modifiers. Strong evidence is the occurrence of a definite article or a possessive. Proper names are also understood as definite: an occurrence of a common name such as “John” carries the assumption that there is some contextually distinguished person named “John”. **MORE**…

@size: This attribute should be assigned a value only if the NP contains a numerical determiner that is not interpreted as expressing involvement, or if the NP is a singular proper name, definite description, or possessive 0 in which case the value “1” should be assigned.

[to be expanded]

Appendix B. Annotated examples

(B1) All the water in these lakes is polluted.

Markables: m1=all the water in these lakes, m2=water in these lakes, m3=water, m4=in these lakes, m5=these lakes, m5=is polluted

QuantML-XML annotation representation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”every” definiteness=”def”/>
<qDomain xml:id=”x2” #target=”#m2” domain=”#x3” restrictions=”#r1”/>
<sourceDomain xml:id=”x3” target=”#m3” pred=”water” indiv=”mass”/>
<ppMod xml:id=”r1” target=”#m4” pRel=”in” pEntity=”#x4” distr=homogeneous
linking=”inverse”/>
<entity xml:id=”x4” #target=”#m5” domain=”#x5” involvement=”all” definiteness=”def”/>
<sourceDomain xml:id=”x5” target=”#m6” pred=”lake” indiv=”count”/>
<event xml:id=”e1” target=”#m7” pred=”pollute”/>
<participation event=”#e1” participant=”#x1” semRole=”patient” distr=”every”
        evScope=”narrow”/>
```

(B2) The boys drank all the beer.

QuantML-XML annotation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=”def”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”boy” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”drink”/>
<entity xml:id=”x3” #target=”#m4” domain=”#x4” involvement=”total” definiteness=”def”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”beer” indiv=”mass”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
evScope=”narrow”/>
<participation event=”#e1” participant=”#x3” semRole=”patient” distr=”individual”
        evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”equal”/>
```

(B3) The crane lifted all the sand.

QuantML-XML annotation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=”def”
        size=”1”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”crane” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”lift”/>
<entity xml:id=”x3” #target=”#m4” domain=”#x4” involvement=”total” definiteness=”def”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”sand” indiv=”mass”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
        evScope=”narrow”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”collective”
        evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”equal”/>
```

(B4) Three breweries supplied fifteen inns

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”3” definiteness=”indef”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”brewery” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”supply”/>
<entity xml:id=”x3” #target=”#m4” domain=”#x4” involvement=”15” definiteness=”indef”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”inn” indiv=”count”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
evScope=”narrow”/>
<participation event=”#e1” participant=”#x3” semRole=”beneficiary” distr=”individual”
        evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”equal”/>
```

(B4) The president did not accept the proposals

```
entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=”def” size=”1”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”president” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”accept”/>
<entity xml:id=”x3” #target=”#m4” domain=”#x4” involvement=”all” definiteness=”def”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”proposal” indiv=”count”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
        evScope=”narrow” polarity=”negative”/>
<participation event=”#e1” participant=”#x3” semRole=”beneficiary” distr=”individual”
        evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”wider”/>
```

[to be expanded]

Appendix C. QuantML Semantics

The QuantML semantics consists of a specification of the meaning of annotation structures through a compositional translation of such structures into DRSs, whose meaning is defined in Discourse Representation Theory (Kamp & Reyle, 1993). This specification makes use of (1) an assignment of semantic values to the elements of the conceptual inventory of the abstract syntax and (2) a set of rules for interpreting entity structures and link structures and their combination as full-blown annotation structures. Section C1 of this appendix specifies this value assignment; Section C2 specifies the interpretation of the various kinds of structures defined by the abstract syntax and Section C3 contains examples of the interpretation of annotations of a number of interesting forms of quantification, such as cumulative quantification, group quantification, and mass NP quantification.

C1 Conceptual inventory items

The elements of the QuantML conceptual inventory are interpreted in one of two ways: (a) in the form of values that are expressed in DRS interpretations by predicates in DRS conditions; (b) in the form of structural properties of DRS interpretations.

Examples of the latter kind are definiteness values (“definite”, “indefinite”) and event scope values (“wide”, “narrow”); their interpretation is embodied in the specification of the interpretation of entity structures, link structures and annotation structures in the clauses C2 -C4 and C31-C32.

The interpretation of elements of the former kind takes the form of an assignment function F_Q from conceptual inventory items to expressions for use in the DRS conditions. This function is defined as follows:

- Predicates that denote source domains or event types (typically corresponding to nouns and verbs), or that correspond to adjectives or prepositions, and which in the abstract syntax are designated by lexical items of the language of the annotated primary data, are also used in DRS conditions, i.e., for such predicates: $F_Q(\mathrm{P}) = \mathrm{P}$. Note that the lexical items used to represent such predicates are derived from the words in the primary data that are identified by markables.
- For semantic roles also the same names are used in the semantic representations as in the annotations.
- The interpretation of a specification of a proportional reference domain involvement, such as ‘all’ and ‘most’, depends on the reference domain, for example, *“most (of the) books are old”* should be interpreted as saying that more than half of (the number of) books in the reference domain are old. The assignment function F_Q therefore assigns to the involvement specification “most” a function $F_Q(\mathrm{most}) = \lambda Z.\ \lambda X.|X| > (|Z_C|/2)$, which can be applied to a domain specification like “book” to produce the predicate $\lambda X.|X| > (|\mathrm{book}_C|/2)$, i.e. the predicate of having more elements than half the number of contextually distinguished books. Similarly, $F_Q(\mathrm{all}) = \lambda Z.\lambda X.\ X{=}Z_0$, $F_Q(\mathrm{total}) = \lambda Z\ \lambda X.\ \cup X{=}\cup Z_0$, $F_Q(\mathrm{a}) = \lambda X.|X| > 0$, and $F_Q(\mathrm{some}) = \lambda Z.\ \lambda X.|\cup X| > 1$ where Z is to be instantiated by a source domain and X by a set of participants from that domain. In a quantification with individual distribution, X is a subset of the reference domain; in a quantification with unspecific distribution, X may also contain subsets of that domain, and a specification of the size of X concerns the number of individuals from the domain that X contains plus the number of elements in the sets of individuals that X contains. Moreover, if a part-whole relation is defined for the individuals of the source domain, then in the case of a quantification with unspecific distribution X additionally contains the objects that are parts of individuals or that are formed by joining individual-parts.
- Numerical predicates that are used to specify absolute domain involvement, reference domain size, the size of certain parts of a reference domain, or the number of repetitions or frequency of recurring events, are also used in DRS conditions: for such predicates $F_Q(\mathrm{q, D}) = \lambda X.\ \mathrm{q}(X_D)$;

- The basic units of measurement, such as ‘meter’, ‘kilogram’, ‘litre’, and ‘hour’, are also used in DRS conditions; for these items $F_Q(u) = u$.

C2 Entity structures

C2.1 Participant structures

The general form of a participant structure is a triple or quadruple < DS, q, d, (N)>, depending on whether a reference domain size N is specified. The component DS is in the simplest case a single unstructured domain specification, i.e. a pair S = <m,<D,v>> consisting of a markable m, a domain predicate D, and a specification of the individuation of D (individuated or not, and if individuated whether or not with internal part-whole structure). In general, DS may contain a sequence of domain specifications and a sequence of modifiers:

(C1) $<<<S_1, S_2,\ldots S_k>, <M_1, M_2,,\ldots M_n>>, q, d, N>$

Each of the domain specifications may in turn include a subsequence of domain specifications and local modifiers. For the annotation of the generalized quantifier expressed by an indefinite NP (d = indef), or more generally if the annotated material gives no reason to introduce a reference domain different from the source domain, the semantic interpretation of the participant structure is as shown in (C3)[10]; the quantitative predicate q’ occurring in (C4)-(C6) is defined in (C2), i.e. by applying $F_Q(q)$ to the result of applying the interpretation $F_Q(v)$ of the individuation specification of the domain specification.[11]

(C2) $q' = F_Q(q)(F_Q(v)$; $F_Q(\text{count}) = \lambda X.X$; $F_Q(\text{mass}) = \lambda X.U^+X$; $F_Q(\text{count/parts}) = \lambda X.U^xX$

For participant structures with an unstructured domain,, the interpretation is defined by the clauses (C3)-(C5). If the reference domain is a contextually determined part of the source domain, then the participant structure is interpreted as in (C4), where D_0 designates the characteristic predicate of the reference domain related with the source domain D.

(C3) $I_Q(<D,v>, q, \text{indef}) = [\ X \mid q'(X), x \in X \rightarrow D(x)\ ]$

(C4) $I_Q(<D,v>, q, \text{def}) = [\ X \mid q'(X), D_0(x) \rightarrow x \in X, x \in X \rightarrow D_0(x)\ ]$

If the annotated NP contains a size specification (‘N’) of the reference domain, then the interpretation of the participant structure is:

(C5) $I_Q(<D,v>, q, \text{def}, N) = [\ X \mid N(|D_0|), q'(X), D_0(x) \rightarrow x \in X, x \in X \rightarrow D_0(x)\ ]$

If v=count/parts then the domain predicate D and $D_{0,}$ in (C3) - (C5) should be replaced by D^x and D_0^x, respectively.

A conjunctive NP head introduces a disjunctive condition instead of the application of a single domain predicate:

---

[10] For the sake of compactness, instead of the usual box notation of DRT also a string notation will be used, with opening and closing square brackets corresponding to boxes, and a horizontal bar to separate the list of discourse referents from conditions. E.g., (67) in this string notation is: $[\ X \mid |X|=3,\ x \in X \rightarrow P(x)\ ]$.

(C6) $I_Q(<<D_1, D_2, \ldots D_k>, q, indef>) = [\ X \mid q'(X),\ x \in X \ \rightarrow [\ \mid D_1(x) \vee D_2(x) \ldots \vee D_k(x)]\ ]$

(C7) $I_Q(<<D_1, D_2, \ldots D_k>, q, def>) = [\ X \mid q'(X),\ x \in X \ \leftrightarrow [\ \mid D_{10}(x) \vee D_{20}(x) \ldots \vee D_{k0}(x)]\ ]$

(C8) $I_Q(<<D_1, D_2, \ldots D_k>, q, def, N>) =$
$[\ X \mid q'(X),\ N(|D_{10} \cup D_{20} \cup \ldots \cup D_{k0}|), x \in X \ \leftrightarrow [\ \mid D_{10}(x) \vee D_{20}(x) \ldots \vee D_{k0}(x)]\ ]$

Entity structures with complex domains

The domain component of a participant structure can be complex in two ways: by the head of the corresponding NP being a conjunction, and by the head (or one of its conjuncts) being modified by adjectives, nouns, PPs or relative clauses. Modifications correspond semantically to restrictions, additional to the one(s) defined by the head noun(s), and they come in four varieties as shown in Table 2 in Section 3.3.1. To show the semantics of the various types of modifications, the following specifications first describe the effect of a single modifier for a non-conjunctive NP head. This is subsequently generalized for multiple modifiers and conjunctive NP heads.

A modifier 'r' used with individual or homogeneous distribution and linear linking introduces an additional condition in the embedded DRS (compared to C3) as shown in (C9a), where r' is short for $I_Q(r)$ and D' for $F_Q(D)$:

(C9a) $I_Q(<<<D, count>, <r, individual, linear>>, q, indef>) =$
$I_Q(<<<D, count/parts>, <r, individual, linear>>, q, indef>) =$
$I_Q(<<<D, mass>, <r, homogeneous, linear>>, q, indef>) = [\ X \mid q'(X), x \in X \ \rightarrow \ [\ \mid D'(x), r'(x)\ ]]$

Similarly for a modifier used with unspecific distribution and linear linking, but in this case the modifying predicate should be generalized from being defined only for individuals (or mass quantities) to also being applicable to *sets of individuals* in the reference domain - see (16) in Section 6.4. This is expressed in (C9b), (Note that X* contains all the elements of X as well as all the subsets.)

(C9b) $I_Q(<<<D,count>, <r,unspec,linear>>, q, indef>) = [X \mid q'(X), x \in X^* \rightarrow [\ \mid D'^*(x), r'^*(x)\ ]$

For the unspecific modification of a mass noun, any specification of the size of the reference domain should be applied to the totality formed by the quantities involved. This is expressed in (C9c).

(C9c) $I_Q(<<<D,mass>, <r,unspec,linear>>, q, indef>) = [X \mid q'(\Sigma(X)), x \in X \ \rightarrow [\ \mid D'(x), r'(x)\ ]$

For the unspecific modification of a head with a count/parts individuation, the entities that the modification applies to are either individuals or parts of individuals. This is expressed in (C9d).

(C9d) $I_Q(<<<D,count/parts>, <r,unspec,linear>>, q, indef>) = [X \mid q'(\Sigma^\wedge(X)), x \in X^\wedge \rightarrow [\ \mid D'^\wedge(x),$
$r'^\wedge(x)\ ]$

A modification with collective distribution introduces, regardless of the individuation of the domain, an additional condition at the DRS top level, as shown in (C9c), where 'v' can be any value:

(C9c) $I_Q(<<<D,v>, <r, collective, linear>>, q, indef>) = [\ X \mid q'(X), r'(X), x \in X \rightarrow \ D'^*(x)]$

The interpretation rules in (C9) all have a counterpart for the corresponding definite case, like (C3) has the definite counterpart (C4), as well as for the definite case with size specification, like (C5).

For a modification with inverse linking the semantic interpretation is obtained most easily by first constructing the interpretation of the linear linking case, and subsequently switching the scopes of the quantifiers involved in the inversion around. For example for the NP *"Three students from every Dutch university"* in (C10) the top-level quantification in the case of the (unlikely) interpretation with linear linking is shown in (C11).

(C10) Three students from every Dutch university participated.

(C11)

```
+-------------------------------------------------------------------+
| X                                                                 |
+-------------------------------------------------------------------+
| |X|=3        +--------------------------------------------------+ |
| x ∈ X  →     | U                                                | |
|              +--------------------------------------------------+ |
|              | student(x)                                       | |
|              | u ∈ U ← [ | dutch(u), university(u) ]            | |
|              | u ∈ U → [ | dutch(u), university(u), from(x,u) ] | |
|              +--------------------------------------------------+ |
+-------------------------------------------------------------------+
```

To obtain the more plausible inversely linked reading, the two quantifications in this DRS are switched around, using the scope-switching operation defined in (C12), to get the result (C13).

(C12) InvScope([X | C1, x ∈ X → [Y | C2, y ∈ Y → N]]) = [Y | C2, y ∈ Y → [X | C1, x ∈ X → N]]

(C13)

```
+-------------------------------------------------------------------+
| U                                                                 |
+-------------------------------------------------------------------+
| u ∈ U ← [ | dutch(u), university(u) ]                             |
|                                                                   |
|              +--------------------------------------------------+ |
|              | X                                                | |
| u ∈ U  →     +--------------------------------------------------+ |
|              | |X|=3, x ∈ X  → student(x)                       | |
|              | x ∈ X → [ | dutch(u), university(u), from(x,u) ] | |
|              +--------------------------------------------------+ |
+-------------------------------------------------------------------+
```

Modifications with inverse linking can be expressed by PPs and (marginally) by relative clauses. The semantic interpretation of PP modifier structures and relative clause structures is described below in Section C2.3.

C2.2 Event structures

If P_E is the characteristic predicate of a certain event domain, as typically named by a verb, then the semantics of an event entity structure with that event domain is given by (C15):

(C15) $I_Q(P_E)$ = [E | e ∈ E → P_E(e)]

The semantics of an event structure for a k-times repetitive event is given by (C16), and for a repetitive event that occurs k times in each period of type P_T by (C17):

(C16) $I_Q(P_E$, k) = [E | k(E), e ∈ E → P_E(e)]

(C17) $I_Q(P_E$, k, $P_T)$ = [E | e ∈ E → P_E(e), [T| P_T(T) → [E', t | |T|=k, t ∈ T, e ∈ E' → [| e ∈ E, AT(e,t)]]]]

C2.3 Modifier structures

C2.3.1 Adjectives

Adjectives are interpreted semantically as one-place predicates that can be used in DRS conditions. They are represented by names that correspond to lexical items of the language of the primary data (see Section 3.4 in the main part of the document).

C2.3.2 Nouns as nominal modifiers

The entity structure for a noun modifying another noun is a pair <m, <N>> consisting of a markable and a property, or a structure $<m, <N, r_1,.., r_n>>$, $n≥1$ where the property (N) is accompanied by a sequence of modifiers. The specification in (C19) of the semantics of a noun modifying another noun follows Hobbs (1993) in introducing the 'anonymous' relation "NN" to indicate the implicit semantic relation between the modifying noun and the noun it modifies (compare the example in (39) in Section 6.7).

(C19) a. $I_Q(<N>) = \lambda z.$ [y | P(y), NN(z,y)]
b. $I_Q(<P, r_1,.., r_n>) = \lambda z.$ [y | P(y), NN(z,y), $r_1(y),\ldots, r_n(y)$]

For example, the expression *"a toxic waste dump"* is interpreted as being about a dump that has some unknown relation to toxic waste. Note that there is an ambiguity here, as illustrated by the example *"an old waste dump"*, which is more plausibly interpreted as an old dump for waste; this means that *"old"* should rather be annotated as a modifier of *"dump"*.

C2.3.3 Relative clause structures

Like adjectives and nominal noun modifiers, a relative clause is interpreted semantically as a one-place predicate that can be used in DRS-conditions, expressing restrictions on a quantification domain. In its linguistic structure, a relative clause (RC) is very much like a main clause, except that one of the (sets of) participants is missing; its role is played by the modified NP head.

As specified in Section 3.3.5, the linguistic information 's_{RC}' in an entity structure $\varepsilon_{RC} = <m,s_{RC}>$ annotating an RC has the form (C20), in which R_a is the 'missing' semantic role and α_{RC} is the annotation structure of the combination of events and participants in the RC.

(C20) $s_{RC} = <R_a$ (semantic role), α_{RC} (annotation structure)>

The component α in s_{RC} has the same structure as the annotation structure of a main clause as specified in (62), repeated here as (C21):

(C21) $\alpha_{RC} = <\varepsilon_{EV}, \{\varepsilon_{P1},\ldots, \varepsilon_{Pn}\}, \{L_{P1},\ldots, L_{Pn}\}, \{sc_1,\ldots, sc_k\}>$

The interpretation of such an annotation structure always has a sub-DRS, embedded within the scope of all the quantifiers in the annotated clause, in which the participants are linked to events in their respective semantic roles. This sub-DRS is called the *nucleus* of the embedding DRS. To construct the interpretation of the RC as a one-place predicate, the condition $R_a(e,z)$ that links the 'missing' participant (z) to the event (e) in the 'missing' semantic role R_a is inserted in the nucleus, and the participant variable is abstracted over. This is expressed schematically in (C22), where 'IN(K,C)' designates the operation of inserting condition C in the nucleus of DRS K, 'evv(K)' designates the event variable of (the nucleus of) DRS K, α' abbreviates $I_Q(\alpha_{RC})$, and R_a' abbreviates $F_Q(R_a)$.[12]

(C22) $I_Q(R_a, \alpha_{RC}) = \lambda z.IN(\alpha', R_a'(evv(\alpha'), z))$

Predicates as defined in (C37) can be substituted for r_1' in (C7) to provide the DRS interpreting the domain specification with a linearly linked RC-restriction with individual, collective, or unspecific distribution, and via scope inversion also for modifications with inverse linking.

C2.3.4 Prepositional phrases as modifiers

The interpretation of a PP-restriction can be described in a similar way as that of a relative clause. In the case of linear linking, the interpretation is built up from the interpretations of the preposition and the NP that constitute the PP. A preposition is assumed here (for simplicity) to denote a binary relation R_P; and an NP to denote a generalized quantifier whose QuantML annotation is a participant entity structure ε_{PP}. The semantic interpretation of the NP has the form (C23), where C_1 and C_2 are sets of conditions.

(C23) $I_Q(\varepsilon_P) = \varepsilon_P' = [\, X \mid C_1, x \in X \rightarrow [\, \mid C_2 \,]]$

To construct the interpretation of the PP as a one-place predicate, the condition $R_P(x,z)$ that relates the modified NP head to the NP in the PP through the PP's relation R_P is added to the conditions C_2 and the variable z is abstracted over:

(C24) $\lambda z. [\, X \mid C_1, x \in X \rightarrow [\, \mid C_2, R_P(x,z) \,]]$

In compositional terms, the predicate in (C40) is constructed as specified in (C25) by inserting the condition $R_P'(qv(\varepsilon_P'), z)$ in the embedded DRS of the participant structure interpretation $\varepsilon_P' = I_Q(\varepsilon_P)$ (accomplished by the operation 'IN_1'), where 'qv(K)' designates the quantified variable in the DRS K (the variable x in (C24)).

(C25) $I_Q(R_P, \varepsilon_P) = \lambda z.\ IN_1(\varepsilon_P', R_P'(qv(\varepsilon_P'), z))$

C3 Link structures

C3.1 Participation links

As already mentioned in (71) above, repeated here as (C30), the semantic interpretation of a participation link is constructed by the DRS-merge of the interpretations of the component event structure, participant structure and triple < R, d, s> or pair < R, d> that contains the linking information.

(C30) $I_Q(<\varepsilon_E, \varepsilon_P, R, d, s>) = I_Q(\varepsilon_P) \cup (I_Q(\varepsilon_E) \cup I_Q(R, d, s))$

The interpretation of triples <R, d, s> and pairs <R, collective> is defined by the following clauses:

(C31) $I_Q(R, individual, narrow) = I_Q(R, homogeneous, narrow) = [\, E, X \mid x \in X \rightarrow [\, e \mid e \in E,\ R(e,x) \,]]$

$I_Q(R, individual, wide) = I_Q(R, homogeneous, wide) = E, X \mid e \in e \rightarrow [\, x \mid x \in X,\ R(e,x) \,]]$

[12] A relative clause that contains quantifiers with equal scope has more than one nucleus, see example (C58). These nuclei all have the same event variable, so the value of 'evv' is still uniquely defined; the insertion operation 'IN' is in that case repeated for every nucleus.

I_Q(R, collective) = [E, X | e ∈ e → R*(e,X)]

I_Q(R, group, narrow) = [E, X | |X| > 1, e ∈ E → R*(e,X)]

I_Q(R, group, wide) = [E | e ∈ e → [X | |X| > 1, R*(e,X)]

I_Q(R, unspecific, narrow) = [E, X | x ∈ X* → [e | e ∈ E, R*(e,x)]

I_Q(R, unspecific, wide) = [E, X | e ∈ E → [x | x ∈ X*, R*(e,x)]

C3.2 Scope links

In the semantics of QuantML annotation structures, the significance of scope links is that they determine how the interpretations of participant structures and event structures should be combined to form annotation structures that correctly represent the correct scope relations among the quantifiers in a clause.

C4 Interpretation of full-blown annotation structures

Conceptually, the unit for quantification annotation is formed by the specification of a set of events and the sets of participants involved. Linguistically, this unit typically corresponds to a clause: a verb with its argument NPs, although instead of a verb also a noun can denote a set of events, such as "concert", "crash", and "meeting". The annotation of such a unit, as noted above, has the structure shown in (62), repeated here:

(C32) $<\varepsilon_{EV}, \{\varepsilon_{P1},..., \varepsilon_{Pn}\}, \{L_{P1},..., L_{Pn}\}, \{sc_1,..., sc_k\}>$

Such structures consist of an event structure, a number of participant structures, participation link structures that relate the participants to the events, and scope relations among the participants. The first three components provide essentially the semantic content of the annotation, while the scope relations (as well as the specification of event scope in participant structures) determine the way these components combine to provide an interpretation, expressed as a DRS.

As noted at the end of Section 7, if the set of scope relations in an annotation structure does not define the relative scopes of every pair of participant structures, then its semantic interpretation is not a single DRS but a set of (sub-)DRSs plus specification of scope constraints, an 'Underspecified DRS' ('UDRS', Reyle, 1993).

C5 Examples

This clause contains examples of the QuantML annotation and interpretation of a variety of quantification forms: collective quantification, cumulative quantification, group quantification, mass noun quantification, proper names, quantification involving parts of individuals, quantification with unspecific distribution, and quantification annotation with underspecified scope relations.

C5.1. Collective quantification

(C51) "The three men moved two pianos"

Upon the collective agent reading for "The three men", the individual reading for "two pianos", and narrow scope of the move-events, the sentence is annotated as follows. Collective quantifiers have wide scope, hence the scope link structure.

Markables: m1=The three men, m2=men, m3=moved, m4=two pianos, m5=pianos

QuantML annotation structure:

$A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle$

$\varepsilon_E = \langle m3, move\rangle$

$\boldsymbol{\varepsilon_{P1}} = \langle m1, \langle\langle m2, man\rangle, 3, definite\rangle\rangle$

$\boldsymbol{\varepsilon_{P2}} = \langle m4, \langle\langle m5, pianos\rangle, 2, indefinite\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, Agent, individual, narrow\rangle$

$L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, Theme, unspecific, narrow\rangle$

$sc_1 = \langle \varepsilon_{P1}, \varepsilon_{P2}, wider\rangle$

XML representation:

```
<entity xml:id="x1" #target="#m1" domain="#x2" involvement="3" definiteness="def"/>
<sourceDomain xml:id="x2" target="#m2" pred="man" indiv="count"/>
<event xml:id="e1" target="#m3" pred="move"/>
<entity xml:id="x3" #target="#m4" domain="#x2" involvement="2" definiteness="indef"/>
<sourceDomain xml:id="x4" target="#m5" pred="piano" indiv="count"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="individual"
evScope="narrow"/>
<participation event="#e1" participant="#x3" semRole="patient" distr="unspecific"
evScope="narrow"/>
<scoping arg1="#x1" arg2="#x3" scopeRel="wider"/>
```

Semantics: "The three men": $[\ X \mid |X| = 3, x \in X \leftrightarrow man_0(x)\ ]$

"two pianos": $[\ Y \mid |Y| = 2, y \in Y \rightarrow piano(y)\ ]$

The interpretation of "moved" corresponds to a set of move-events which, neglecting the past tense, is interpreted as the DRS $[\ E \mid e \in E \rightarrow move(e)\ ]$. The collective agent relation is interpreted as the DRS $[\ E, X \mid e \in E \rightarrow agent^*(e, X)\ ]$ and the individual theme relation, with narrow event scope, as the DRS $[\ E, Y \mid y \in Y \rightarrow [\ e \mid e \in E, theme(e, y)\ ]$

Because of the scope link structure, interpretation of the annotation structure is obtained by scoped merging of the two participant link structures:

(C52) $I_Q(A) = I_Q(\langle \varepsilon_E, \{\varepsilon_{P1},\varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), \langle \varepsilon_{P1},\varepsilon_{P2},wider\rangle\rangle) = I_Q(L(\varepsilon_E,\varepsilon_{P1}) \cup^s I_Q(L(\varepsilon_E,\varepsilon_{P2}))=$

$[\ E, X \mid e \in E \rightarrow move(e), |X| = 3, x \in X \rightarrow [\ Y \mid |Y| = 2, y \in Y \rightarrow$

$[\ e \mid e \in E, agent^*(e, X), theme(e, y)\ ]]]$

C5.2 Cumulative quantification:

(C55) Three breweries supplied fifteen inns

Annotation structure:

$A = \langle\{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), \{\langle \varepsilon_{P1},\varepsilon_{P2},equal\}\rangle\rangle$

$\boldsymbol{\varepsilon_{P1}} = \langle m1, \langle\langle brewery,count\rangle, 3, indef\rangle\rangle$

$\boldsymbol{\varepsilon_{P2}} = \langle m3, \langle\langle inn,count\rangle, 15, indef\rangle\rangle$

ε_E = <m2, supply>
L($\boldsymbol{\varepsilon_E}$, $\boldsymbol{\varepsilon_{P!}}$) = <$\boldsymbol{\varepsilon_E}$, $\boldsymbol{\varepsilon_{P!}}$, Agent, individual, narrow>
L($\boldsymbol{\varepsilon_E}$, $\boldsymbol{\varepsilon_{P2}}$) = <$\boldsymbol{\varepsilon_E}$, $\boldsymbol{\varepsilon_{P2}}$, Beneficiary, individual, narrow>
sc_1 = <ε_{P1}, ε_{P2}, equal>

The semantic interpretation of an annotation structure with a 'equal scope' relation between two participant structures involves the use of a merge operation that slightly differs from the 'scoped merge' operation; this operation is called 'dual-scope merge' and symbolised by $\cup^{=}$, and is defined as follows. The operation is defined for two arguments that both have the form shown in (C56):

(C56a) $[\ X, E \mid C_1(X), C_2(E), x \in X \rightarrow K_1\ ]$
(C56b) $[\ Y, E' \mid C_3(Y), C_4(E'), y \in Y \rightarrow K_2\ ]$

where $C_1(X)$, $C_2E)$, $C_3(Y)$ and $C_4(E')$ are sets of conditions, such as the specification of a cardinality, and K_1 and K_2 are any DRSs. The 'dual-scope merge' $\cup^{=}$ of two such arguments is defined by (C57), and its use in specifying the semantics of the annotation structure in (C55) is illustrated by (C58).

(C57) $[\ X, E \mid C_1(X), C_2(E), x \in X \rightarrow K_1\ ] \cup^{=} [\ Y, E' \mid C_3(Y), C_4(E'), y \in Y \rightarrow K_2\ ] =$

$= [\ X, Y, E \mid C_1(X), C_2(E), C_3(Y), x \in X \rightarrow K_1 \cup (K_2 \cup [\ y \mid y \in Y\ ]), y \in Y \rightarrow$
$K_2 \cup (K_1 \cup [\ x \mid x \in X]]$

(C58) $I_Q(A) = I_Q(<\varepsilon_E, \{\varepsilon_{P1},\varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), <\varepsilon_{P1}, \varepsilon_{P2}, \text{equal}>>) = I_Q(L(\varepsilon_E,\varepsilon_{P1}) \cup^{=} I_Q(L(\varepsilon_E,\varepsilon_{P2}))$
$= [X, Y, E \mid |X|=3, e \in E \rightarrow \text{supply}(e),\ x \in X \rightarrow [e, y \mid e \in E, y \in Y, \text{brewery}(x), \text{inn}(y),$
$\text{agent}(e,x), \text{beneficiary}(e,y)], y \in Y \rightarrow [e, x \mid e \in E, x \in X, \text{brewery}(x),$
$\text{inn}(y), \text{agent}(e,x), \text{beneficiary}(e,y)]] =$

<table>
<tr><td colspan="2">E, X, Y</td></tr>
<tr><td colspan="2">|X|=3, |Y|=2, e ∈ E → supply(e), x ∈ X → brewery(x), y ∈ Y → inn(y)</td></tr>
<tr><td>x ∈ X →</td><td><table><tr><td>e y</td></tr><tr><td>e ∈ E, y ∈ Y
agent(e,x), theme(e,y), beneficiary(e,y)</td></tr></table></td></tr>
<tr><td>y ∈ Y →</td><td><table><tr><td>e x</td></tr><tr><td>e ∈ E, x ∈ X
agent(e,x), theme(e,y), beneficiary(e,y)</td></tr></table></td></tr>
</table>

C5.3 Group quantification
(C59) Seven boys played against eleven girls.

Markables: m1 = "seven boys", m2 = "boys", m3 = "played", m4 = "eleven girls", m5 = "girls"

Upon the reading that groups of boys played with groups of girls (see example (30) in Section 6.6 in the main text), the QuantML annotation structure and concrete representation are as follows:

Annotation structure: A = $\langle\{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), \{\langle\varepsilon_{P1},\varepsilon_{P2}$,unscoped$\}\rangle\rangle$

ε_{P1} = <m1, <<boy,count>, 7, indef>>

ε_{P2} = <m3, <<girl,count>, 11, indef>>

ε_E = <m2, play>

$L(\varepsilon_E, \varepsilon_{P!}) = \langle\varepsilon_E, \varepsilon_{P!}$, Agent, group, wide>

$L(\varepsilon_E, \varepsilon_{P2}) = \langle\varepsilon_E, \varepsilon_{P2}$, Agent, group, wide>

$sc_1 = \langle\varepsilon_{P1}, \varepsilon_{P2}$, unscoped>

Annotation representation:

<entity xml:id="x1" #target="#m1" domain="#x2" involvement="7" definiteness="indef"/>
<sourceDomain xml:id="x2" target="#m2" pred="boy" indiv="count"/>
<event xml:id="e1" target="#m3" pred="play"/>
<entity xml:id="x3" #target="#m4" domain="#x2" involvement="11" definiteness="indef"/>
<sourceDomain xml:id="x4" target="#m5" pred="girl" indiv="count"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="group" evScope="wide"/>
<participation event="#e1" participant="#x3" semRole="agent" distr="group" evScope="wide"/>
<scoping arg1="#x1" arg2="#x3" scopeRel="unscoped"/>

Semantics:

Apply the scoped merge operation as defined above in Section 3.6.3, (83) – (85), to the participation link structures and the participant entity structures, and in view of the scoping relation being 'unscoped', combine the interpretations by the ordinary DRS merge.

$I_Q(A) = I_Q(\langle\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2})\}, \{\varepsilon_{P1},\varepsilon_{P2},\text{unscoped}\}\rangle) = I_Q(L(\varepsilon_E,\varepsilon_{P1}) \cup I_Q(L(\varepsilon_E,\varepsilon_{P2}))$
$I_Q(L(\varepsilon_E,\varepsilon_{P1}) = I_Q(\langle\varepsilon_E, \varepsilon_{P1}, \text{Agent, group, wide}\rangle) = (I_Q(\varepsilon_E) \cup I_Q(\text{Agent, group, wide})) \cup^s I_Q(\varepsilon_P)$

$I_Q(L(\varepsilon_E,\varepsilon_{P2}) = I_Q(\langle\varepsilon_E, \varepsilon_{P2}, \text{Agent, group, wide}\rangle) = (I_Q(\varepsilon_E) \cup I_Q(\text{Agent, group, wide})) \cup^s I_Q(\varepsilon_{P2})$

Result:

$[\ E \mid e \in E \rightarrow [\ X, Y \mid |X| = 7, |Y| = 11, x \in X \rightarrow boy(x), y \in Y \rightarrow girl(y), play(e),$
$agent(e, X), agent(e, Y)\ ]$

or in box notation:

E	
$e \in E \rightarrow$	X Y $\|X\| = 7, \|Y\| = 11$ $x \in X \rightarrow boy(x), \; y \in Y \rightarrow girl(y)$ $play(e), \; agent(e,X), agent(e,Y)$

C5.4 Mass noun quantification

(C60) The boys drank all the beer.

Markables: m1=The boys, m2=boys, m3=drank, m4=all the beer, m5=beer

QuantML annotation structure: A = $<\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}>$

ε_E = <m3, drink>

$\boldsymbol{\varepsilon_{P1}}$ = <m1, <<m2, boy>, all, definite>>

$\boldsymbol{\varepsilon_{P2}}$ = <m4, <<m5, beer>, total, definite>>

$L_{P1} = <\varepsilon_E, \varepsilon_{P1}$, Agent, individual, narrow>

$L_{P2} = <\varepsilon_E, \varepsilon_{P2}$, Theme, unspecific, defnite>

$sc_1 = <\varepsilon_{P1}, \varepsilon_{P2}$, equal>

XML representation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=”def”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”boy” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”drink”/>
<entity xml:id=”x3” #target=”#m4” domain=”#x2” involvement=”total” definiteness=”def”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”beer” indiv=”mass”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
        evScope=”narrow”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”unspecific”
        evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”equal”/>
```

Semantic interpretation of the entity structure for “*all the beer”*:

(C61) $I_Q(\varepsilon_{P2})=I_Q(\text{beer,total,definite})=$

X
$\Sigma(X) = \Sigma(beer_0)$
$x \in X \rightarrow beer_0(x)$

The other components of the annotation structure are interpreted as before, so the final result is:

$I_Q(<\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}>) = I_Q(L(\varepsilon_E,\varepsilon_{P1}) \cup^{=} I_Q(L(\varepsilon_E,\varepsilon_{P2})) =$

(C62)

X Y E
$x \in X \leftrightarrow boy_0(x)$, $y \in Y \rightarrow beer_0(y)$, $\Sigma(Y) = \Sigma(beer_0)$ $e \in E \rightarrow drink(e)$
$x \in X \rightarrow$ [e y | $e \in E$, $y \in Y$; agent(e,x), theme(e,y)]
$y \in Y \rightarrow$ [e x | $e \in E$, $x \in X$ ...]

In words, this DRS says that there is a set Y of quantities of beer that together make up all the contextually relevant beer, and a set E of drink-events such that each of the boys in the set X of contextually relevant boys (forming the reference domain of the quantifier *"the boys"*) drank some of the quantities of beer, and each of the quantities of beer was drunk by one of those boys.

C5.5 Proper names

Example (4) of the main document, repeated here as (C63), illustrates the annotation and interpretation of proper names. Quantifications corresponding to proper names do not have a delimited scope; they can be viewed as scopeless, but also as having scope over any other quantification in the same clause. A practical way of dealing with this is to use scope link structures, like sc_1 in this annotation, in the case that there is only one such quantification within the clause, and in the case of multiple proper names assign (rather arbitrarily) scope relations that follow the left-right order of their occurrence. Example (C64) illustrates this.

(C63) Santa gave the children a present

Markables: m1=Santa, m2=gave, m3=the children, m4=children, m5=a present, m6=present

QuantML annotation structure:

$A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}, \varepsilon_{P3}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), L(\varepsilon_E,\varepsilon_{P3})\}, \{ sc_1 , sc_2\}\rangle$

$\varepsilon_E = \langle m2, \langle give\rangle\rangle$

$\varepsilon_{P1} = \langle m1, \langle\langle\langle m1,santa\rangle, count\rangle, all, def\rangle\rangle$

$\varepsilon_{P2} = \langle m3, \langle\langle m4,\langle child\rangle,count\rangle, all, def\rangle\rangle$

$\varepsilon_{P3} = \langle m5, \langle\langle\langle m6,present\rangle, count\rangle, a, indef\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, Agent, individual, narrow\rangle$

$L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, Beneficiary, unspecific, narrow\rangle$

$L_{P3} = \langle \varepsilon_E, \varepsilon_{P3}, Theme, unspecific, narrow\rangle$

$sc_1 = \langle \varepsilon_{P1}, \varepsilon_{P2}, wider\rangle$

$sc_2 = \langle \varepsilon_{P2}, \varepsilon_{P3}, wider\rangle$

Annotation representation:

```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="all" definiteness="def" size="1"/>
<sourceDomain xml:id="x2" target="#m1" indiv="count" pred="santa"/>
<event xml:id="e1" target="#m2" pred="give"/>
<entity xml:id="x3" #target="#m3" domain="#x4" involvement="all" definiteness="def"/>
<sourceDomain xml:id="x4" target="#m4" indiv="count" pred="child" />
<entity xml:id="x5" target="#m5" domain="#x6" involvement="a" definiteness="indef"/>
<sourceDomain xml:id="x6" target="#m6" indiv="count" pred="present"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="individual"/>
<participation event="#e1" participant="#x3" semRole="beneficiary" distr="individual"/>
<participation event="#e1" participant="#x5" semRole="theme" distr="individual"/>
<scoping arg1="#x1" arg2="#x3" scopeRel="wider"/>
<scoping arg1="#x3" arg2="#x5" scopeRel="wider"/>
```

Annotation interpretation:

$I_Q(\varepsilon_{P1}) = [\ X \mid |X|=1,\ x \in X \leftrightarrow santa_0(x)\ ]$

$I_Q((\varepsilon_{P2}) = [\ Y \mid y \in Y \leftrightarrow child_0(y)\ ]$

$I_Q((\varepsilon_{P3}) = [\ Z \mid z \in Z \rightarrow present(z)\ ]$

$I_Q((\varepsilon_E) = [\ E \mid e \in E \rightarrow give(e)\ ]$

$I_Q(L_{P1}) = I_Q(\varepsilon_{P1}) \cup^s I_Q((\varepsilon_E) =$
$[\ X, E \mid e \in E \rightarrow give(e),\ |X|=1,\ x \in X \leftrightarrow santa_0(x),\ x \in X \rightarrow [\ e \mid e \in E, agent(e.x)\ ]\ ]$

$I_Q(L_{P2}) = I_Q(\varepsilon_{P2}) \cup^s I_Q((\varepsilon_E) =$
$[\ Y, E \mid e \in E \rightarrow give(e),\ y \in Y \leftrightarrow child_0(y),\ y \in Y \rightarrow [\ e \mid e \in E, beneficiary(e.y)\ ]$

$I_Q(L_{P3}) = I_Q(\varepsilon_{P3}) \cup^s I_Q((\varepsilon_E) =$
$[\ Z, E \mid e \in E \rightarrow give(e),\ z \in Z \rightarrow [\ e \mid present(z),\ e \in E, theme(e.z)\ ]$

$I_Q(A) = \cup^{s3}(I_Q(L_{P1}), I_Q(L_{P2}), I_Q((L_{P3})) =$
$[\ X, E \mid e \in E \rightarrow give(e),\ |X|=1,\ x \in X \leftrightarrow santa_0(x),\ x \in X \rightarrow [\ Y \mid y \in Y \leftrightarrow child_0(y),$
$y \in Y \rightarrow [\ Z \mid z \in Z \rightarrow [\ e \mid present(z),\ e \in E, agent(e.x), beneficiary(e.y), theme(e.z)\ ]$

Note: $\cup^{s3}$ is the three-place scoped merge operation defined in Section 3.6.3 in the main document; see (85).

Example (C64) illustrates the handling of clauses with more than one proper name.

(C64) Santa brought the presents to Xandra.

Markables: m1=Santa, m2=brought, m3=the presents, m4=presents, m5=Xandra

QuantML annotation structure:

$A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}, \varepsilon_{P3}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), L(\varepsilon_E,\varepsilon_{P3})\}, \{ sc_1 , sc_2\}\rangle$

$\varepsilon_E = \langle m2, \langle bring\rangle\rangle$

$\varepsilon_{P1} = \langle m1, \langle\langle\langle m1, santa\rangle, count\rangle, all, def, 1\rangle\rangle$

$\varepsilon_{P2} = \langle m3, \langle\langle\langle m4, present\rangle, count\rangle, all, def\rangle\rangle$

$\varepsilon_{P3} = \langle m5, \langle\langle\langle m6, xandra\rangle, count\rangle, all, def, 1\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, Agent, individual, narrow\rangle$
$L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, Goal, individual, narrow\rangle$
$L_{P3} = \langle \varepsilon_E, \varepsilon_{P3}, Theme, unspecific, narrow\rangle$
$sc_1 = \langle \varepsilon_{P1}, \varepsilon_{P2}, wider\rangle$, $sc_2 = \langle \varepsilon_{P1}, \varepsilon_{P3}, wider\rangle$, $sc_1 = \langle \varepsilon_{P3}, \varepsilon_{P2}, wider\rangle$

Annotation representation:

```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="all" definiteness="def"
        size="1"/>
<sourceDomain xml:id="x2" target="#m1" indiv="count" pred="santa"/>
<event xml:id="e1" target="#m2" pred="bring"/>
<entity xml:id="x3" #target="#m3" domain="#x4" involvement="all" definiteness="def"/>
<sourceDomain xml:id="x4" target="#m4" indiv="count" pred="present" />
```

<entity xml:id=”x5” target=”#m5” domain=”#x6” involvement=”all” definiteness=”def” size=”1”/>
<sourceDomain xml:id=”x6” target=”#m6” indiv=”count” pred=”xandra”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”individual”/>
<participation event=”#e1” participant=”#x5” semRole=”goal” distr=”individual”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”wider”/>
<scoping arg1=”#x3” arg2=”#x5” scopeRel=”wider”/>
<scoping arg1=”#x3” arg2=”#x5” scopeRel=”wider”/>

Semantics:

$I_Q(A) = \cup^{s3}(I_Q(L_{P1}), I_Q((L_{P3}), I_Q(L_{P2})) =$
$[\, X, E \mid e \in E \rightarrow give(e), |X|=1, x \in X \leftrightarrow santa_0(x), x \in X \rightarrow [\, Y \mid |Y|=1, y \in Y \leftrightarrow xandra_0(y),$
$y \in Y \rightarrow [\, Z \mid z \in Z \rightarrow [\, e \mid present(z), e \in E, agent(e,x), goal(e,y), theme(e,z) \,]]]]$

C5.6 Quantification involving parts of individuals

(C65) Mario ate two and a half pizzas.

Markables: m1=Mario, m2=ate, m3=two and a half pizzas, m4=pizzas

QuantML annotation structure:

$A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\} \rangle$
$\varepsilon_E = \langle m2, eat \rangle$
$\boldsymbol{\varepsilon_{P1}} = \langle m1, \langle\langle Mario, count \rangle, single, definite, 1 \rangle\rangle$
$\boldsymbol{\varepsilon_{P2}} = \langle m3, \langle\langle pizza, count/parts \rangle, 12.5, indefinite \rangle\rangle$
$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, Agent, individual, narrow \rangle$
$L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, Theme, unspecific, narrow \rangle$
$sc_1 = \langle \varepsilon_{P1}, \varepsilon_{P2}, equal \rangle$

Annotation representation:

<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=”def” size=”1”/>
<sourceDomain xml:id=”x2” target=”#m1” pred=”mario” indiv=”count”/>
<event xml:id=”e1” target=”#m2” pred=”eat”/>
<entity xml:id=”x3” #target=”#m3” domain=”#x4” involvement=”2.5” definiteness=”indef”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”pizza” indiv=”countParts”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”infividual”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”wider”/>

Semantics:

$I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\} \rangle) =$
$[\, E, X \mid e \in E \rightarrow eat(e), |X|=1, x \in X \leftrightarrow mario_0(x), x \in X \rightarrow$
$[\, Y \mid |Y|^x = 2.5, y \in Y \rightarrow [\, e \mid e \in E, pizza^\wedge(y), agent(e, x), theme^\wedge(e,y) \,]$