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Semantic Annotation of Quantification in Natural Language

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Abstract

This report describes an approach to the semantic annotation of quantification in natural language. Its main purpose is to lay the groundwork for an interoperable annotation scheme that would fit into the ISO Semantic Annotation Framework (SemAF, ISO 24617). The approach, called QuantML, 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 applies the ISO Principles of semantic annotation (ISO 24617-6:2016).

1 Introduction

Quantification phenomena occur in almost every sentence, and their interpretation is of crucial importance for correctly extracting information from a spoken or written text, but no annotation scheme has yet been proposed for these phenomena. The ISO-TimeML annotation scheme for time and events (ISO 24617-1) has some limited 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, 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 ('ISO-Space') also makes use of the @quant attribute, applying it to spatial entities, and in addition uses the attribute @scopes to specify a scope relation. If the @scopes attribute in a <spatialEntity> element, identified by @xml:id=*"x",* has the value *"y"*, which identifies another spatial entity, then this means that the "x" quantifier has scope over the "y" quantifier. The following example 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=ss1, frameType=intrinsic,
        referencePt=se2, projective=false)
```

This annotation 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/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 "give" 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; Champollion, 2015), and in computational semantics (Alshawi, 1990; Bos, 1995; Hobbs & Shieber, 1987; Pinkal, 1999; Pulman, 2000; Schwertel, 2005). 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. It was noted in logical studies (see Mostowski, 1957; Lindström, 1966) 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* (GQT). 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 ($\forall$, ‘for all’) and existential ($\exists$, ‘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 ‘$\forall$x. p’ and ‘$\exists$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).

Not all quantifiers in natural language are noun phrases; temporal and spatial quantifiers may be expressed by adverbial expressions *("never", "somewhere",...)* Not all noun phrases have to be viewed as quantifiers, either: proper names and singular definite expressions may be regarded as referring rather than quantifying expressions, and a noun phrase in predicative position (as in *"Tim is a teacher"*) may be treated as a predicate.

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

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. Alternatively, representation (6b) can be read as: for each child x there is a present y and a "give"-event e in the past with Santa as the agent, x as the beneficiary, and y as the object that was given. The choice, 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 annotation scheme defined here 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.

[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.

2.2 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 certain 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.

(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 the contextually determined subset of a source domain that is 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 intended referents participating in the events under consideration.

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 explicit 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 and determinacy

Definiteness is a morphological category with a language-dependent marking; 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 "*<u>the</u> book*" in English, and *"bo<u>gen</u>"* in Danish.[2] Other expressions that are also considered to be definite include NPs with a demonstrative pronoun ("*those shoes*") or a 'universal' determiner (*"every man", "all men".*), and with a possessive pronoun ("*my house*") or a genitive *("Mary's dog")*. Proper names and personal pronouns such as "*she*" and "*you*" are also usually counted as definite.[3] Determinacy, on the other hand, is the semantic property of referring to some particular and determinate entity or collection of entities (Peters and Westerståhl, 2013). Loosely speaking, definite expressions are ordinarily used in that way, but the relation between definiteness and determinacy is not straightforward - see (21a) below for an example of a syntactically indefinite NP which, due to a particular stress pattern, is used in a determinate way.

The meaning of definite expressions is the subject of a vast amount of literature (see e.g. Von Heusinger, 2011; Abbott, 2004; 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 (Lewis, 1979), 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).

(12a) <u>The committee members</u> went out to lunch

(12b) <u>All of the committee members</u> went out to lunch

Two much debated issues concerning definiteness, which are important for a GQT-based approach to their interpretation, are 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,

[2] See e.g. Kramsky (1972) on the expression of definiteness in large number of languages.
[3] See Abbott (2004) and Zwarts (1994) for overviews of so-called 'definite expressions' and Abbott (2010, 2017) for a survey of issues relating to definiteness and referring expressions.

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 mostly correct for NPs used as arguments of a verb, which corresponds to NPs used as quantifiers over participants in events, but not necessarily within the scope of a negation (see 13a)), and more generally not for predicative NPs, i.e. NPs used in combination with a copula to construct a predicate, in which case the uniqueness assumption does not hold, (see 13b,c)).

(13) a. Anna did not give the only invited talk at the conference.
b. Scott is not the only author of Waverley.
c. Is Scott the only author of Waverley?

NPs with a possessive expression in central determiner position and without a pre-determiner are definite when the possessive expression is a pronoun or a proper name, as in *"my house"* or *"Tom's two children"*, but in general NPs with a possessive determiner expression are indefinite (Peters and Westerståhl, 2013), contrary to widespread belief (see e.g. Abbott, 2004).

Indefinite NPs (singular or plural), definite plural NPs, and mass NPs differ from definite singular NPs 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 Distributivity

The distributivity (or 'distribution') 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 (14) 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.

(14) 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 (15).

(15) 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 (15a) reads as follows: there is a collection X of cardinality 2, which consists of men, and there is a piano y and a carry-event e such that X is the agent of that event e and the piano y is the theme.. Representation (15b) reads: there is a collection X of cardinality 2, which consists of men, and each of these men is the agent of a carry-event where some vegetables are the theme.

Regarding the analysis represented in (15a), the 'collection' X is most easily thought of as a set in the mathematical sense. However, a set in this sense is an abstract notion, and as such seems to be of the wrong type to function as the agent of an event. Intuitively, sets do not carry vegetables. It is partly for this reason that instead of a set-theoretic approach a lattice-theoretic approach has been proposed (Link, 1983; Landman, 1991), which uses a 'sum' operator to form a composite individual 'a + b' by joining two individuals 'a' and 'b'. The relation between a composite individual and its components is a formal part-whole relation. Whether stipulating that the sum of two individuals is again an individual helps to resolve the collective participant type

[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.

issue is not clear; a lattice is an abstract mathematical construct, just like a set[5], and saying that the sum of two individuals is carrying vegetables seems no less strange than saying that a set of two individuals is carrying vegetables. Kamp & Reyle (1993, pp. 404-405) show that a set-theoretic and a lattice-theoretic approach are formally equivalent (at least as far as the interpretation of plural and singular count nouns is concerned; quantification involving mass nouns is considered in Section 2.8), and are readily converted into one another. Here we follow a set-theoretic approach to the formal semantics of annotation structures, acknowledging that the collective-individual distinction does not primarily concern the type of participant, but rather the way in which multiple participants are involved in an event: collectively or individually. Annotation structures will therefore express collectiveness as a property of the way in which a set of participants is involved in an event; for example, in the annotation of (14a) the agent relation will be marked as collective.

There is more to the distribution of a quantification than just the distinction between collective and individual (also called 'distributive'). Consider sentence (16a), which is structurally very similar to (14a), uttered in a context where the promise expressed in (16b) had been made:

(16) 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, (16a) is not ambiguous in the same way as (13a) for in the context established by (16b) the speaker does not want to suggest that the three boys designated by *"you"* in (16b) 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 lighter ones (maybe even several in one go). This means that the distribution of the quantification is neither collective nor individual; the term 'unspecific' has been used for this distribution (Bunt, 1985).

Following Link (1983) and Kamp & Reyle (1993), the notation X* is used 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 (16a) can be represented in second-order predicate logic as follows:

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

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 (16a), 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 (18a). 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 (18a) as describing a set of events in which Mario has eaten some

[5] In fact, a lattice is defined as a partially ordered set with certain formal properties.

pieces of pizza, adding up to a total of three pizzas, can be represented by (18b), where the notation ‘$P^{\wedge}$’ 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 (18b) 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.[6]

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

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

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 (19a). Presumably, each of the men mentioned in (19a) individually had a beer, and collectively they 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 relation that describes the participation of the men in the drink- and carry- events, as in the annotation fragment shown in (19b), where the XML element ‘srLink’, defined in ISO 24617-4, has been extended with the attribute ‘distr’:

(19) 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 (19a) *“The men”* is replaced by *“Each man*“or 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 carry 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 (20), the central determiner *“twenty-seven”* designates the cardinality of the reference domain, while the predeterminer *“twenty-five”* indicates the cardinality of the subset of the reference domain whose members were involved in vote-events. In (14a) above, the determiner “two” designates the size of a group of men collectively involved in an event.

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

[6] 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 it may not be possible to physically join the four parts and form two well-formed pizzas. The join operator ‘$\Sigma^{\wedge}$’ corresponds to the more abstract idea of joining parts of individuals.

So at least the following quantitative aspects of a quantification must 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 sets, groups, or sums of individuals that are involved in a collective predication.

The meaning of a cardinal determiner may depend on the speaker's intention, as expressed by the stress pattern of an utterance in which it is used. Used with focal stress, "*two*" may give rise to a partitive interpretation; for example, in (21a) "*two salesmen*" means "*two of the salesmen*", different from (21b) where the stress is on "*salesmen".*

(21) a. TWO salesmen came in.
b. Two SALESmen came in.

The occurrence of a cardinal determiner in focus relates also to the much debated issue whether a determiner (or a numeral) like "*two*" should be interpreted as "exactly two", as "two or more", or as "at most two". Consider the following examples:

(22) a. Two dogs are growling.
b. Do you have two AA batteries?
c. How many children does Mary have? Mary has two children.

The standard GQT interpretation of quantifiers of the form "two N" is the property of being a set that contains two Ns. So for example, in DRT (Kamp and Reyle, 1993) sentence (22a) is interpreted as claiming the existence of a set X of two elements that are dogs and growling. Now suppose there are in fact three growling dogs - in that case it is also true that there are two growling dogs. So *"two"* in (22a) is in fact interpreted as "two or more". This seems reasonable for sentence (22a). For sentence (22b), uttered in a context where the speaker is examining a remote control with two apparently flat batteries, this is the only reasonable interpretation. But in (22c) the answer to the question licences the inference that Mary does not have more than two children, so in this case *"two"* means "exactly two". It is widely assumed (e.g. Partee, 1986; Kamp and Reyle, 1993; Krifka, 1999) that the numeral *"two"* indicates that the cardinality of the set (or individual sum) denoted by the NP that it modifies is exactly 2, but that the generalized quantifier *"two N"* is interpreted in some contexts as "at least two N" and in others as "exactly two N", due to context-specific (Gricean) pragmatic inferences - see Kadmon (2001). Quantifier readings of the type "exactly two N" are called 'exhaustive', and can be thought of as generated by a covert operator that could be lexicalized as "only". In (22), replacing *"two"* by *"only two"* in case a and case c enforces or reinforces the "exactly two" reading, whereas in case b the replacement would be distinctly odd for the intended meaning of the question. Similar issues arise when *"two"* forms part of a monotone-decreasing quantifier, as in (22d), which is inherently exhaustive. The exhaustiveness of a quantifier relates to focus placement, as illustrated by (21a). For a detailed discussion of quantification with cardinal determiners see Szabolcsi (2010), Section 9.2.

Sentence (23a) 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 (23b), treating events as individual entities. This can be annotated as in (23c), 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'.

(23) 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="det"
        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 *"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. This way of specifying the size of a set of individuals and parts of individuals is a generalization of the specification of the cardinality of a set of individual objects. The involvement of the reference domain in a mass NP quantification often takes the form of specifying amounts of weight, volume, or another dimension, as in *"one pound of sugar", "two and a half litres of juice".* See further Section 2.8.

2.6 Scope

2.6.1 Relative participant 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 (24), where one interpretation is that the NP *"Everyone in this room"* outscopes 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.

(24) Everyone in this room speaks two languages.

Quantifier scope ambiguities are a nightmare from a computational point of view: a sentence with k NPs 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 (25), containing five NPs, with 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 ambiguity.

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

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 (26) (due to Reyle, 1993):

(26) 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 set A of three breweries and a set 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 mutually outscope each other. 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 (27a) has the same syntactic form as the one in (26), but here the intended reading is not cumulative; it is from a report about a football tournament 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 (26b) 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 B; the scope relation in this case is called ‘unscoped’).

(27) 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.

2.6.2 Event scope

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 (28a). Besides the reading that comes down to saying that everyone is mortal, which can be represented in predicate logic as $\forall x\ [person(x) \rightarrow will\text{-}die(x)]$, or as in (28a) using explicit events, there is also a reading which predicts an apocalyptic future event in which everyone will die. (This interpretation requires the consideration of events in which multiple participants occupy the same role. In contrast with some other approaches, the ISO approach to semantic role annotation (ISO 24617-4), does allow this.)

There is no way to represent this second reading without explicitly introducing events; (28)a. and (28)b. show how both readings can be represented in first-order logic by assigning alternative relative scopes to the quantifications over events and participants:

(28) a. Everyone will die.

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

c. $\exists e\ [die(e) \wedge future(e) \wedge \forall x\ [person(x) \rightarrow theme(e,x)]]$

Quantifications over events tend to have narrow scope. Champollion (2015) claims that event quantification *always* has narrow scope compared to the scope of quantified arguments but this is a context-dependent issue, as the example in (29) illustrates. The interpretation of (29a). as describing a single event with multiple participants, is annotated in (29b), where the XML element ‘srLink’ has been enriched with the attribute ‘evScope’ to indicate the relative scope of the events and the participants.

(29) 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”/>

2.6.3 Negation scope

The QantML scheme does not offer a general treatment of the annotation of polarity and modality, but it provides devices for dealing with the relative scopes of quantifications and negations. The example sentence in (30a) illustrates the possible scopes of a negation at sentence (or clause) level. On the reading in (30)b. the negation scopes over the entire clause; in (30)c the quantifier *“the unions”* scopes over the negation.

(30) a. The unions do not accept the proposal.
b. It is not the case that all the unions accept the proposal

c. All the unions do not accept the proposal (none of them does)

The readings (30b) and (30c) are distinguished in annotations by introducing a @polarity attribute for participation link structures with the value “wide negative” for wide-scope negation (case (30b); see (31b)) and the value “narrow negative” for narrow-scope negation (case (30c)); see (31c)).

(31) a. The unions do not accept the proposal.
b. <srLink event=”#e1” participant=”#x1” semRole=”agent” distr=”individual” polarity=”neg-wide”/>
c. <srLink event=”#e1” participant=”#x1” semRole=”agent” distr=”individual” polarity=”neg-narrow”/>
d. <entity xml:id=”x1” target=”#m1” entityType=”union” involvement=”not-all”/>

Note that this way of annotating negation scopes makes it possible to also handle cases of double or triple negation, such as *“Not all the unions do not accept the proposal”* and even *“It is not the case that not all the unions do not accept the proposal”.*

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 (32a) 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 (32b) and (32c)[7], 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 (32d, e) 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 (17) above, the notation with a subscript ‘0’ as in ‘$book_0$’ is used here to indicate that the reference domain of the phrase *“these 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”.*

(32) a. These books are heavy.

b. $\exists X\, [\forall x\, [x \in X \leftrightarrow [book_0(x) \wedge \exists e\, [heavy(e) \wedge theme(e,x)]]]]$

c. $\exists X\, [\forall x\, [x \in X \leftrightarrow book_0(x)] \wedge \exists e\, [heavy(e) \wedge theme(e,X)]]$

d. $\exists X\, [\forall x\, [x \in X \leftrightarrow [book_o(x) \wedge heavy(x)]]]$

e. $\exists X\, [\forall x\, [x \in X \leftrightarrow book_0(x))] \wedge heavy^*(X)]$

Example (32) illustrates the predicative use of an adjective; the attributive use is illustrated in (33), which displays the same ambiguity as the predicative use. 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. $\exists X\, [\forall x\, [x{\in}X \leftrightarrow [book_0(x) \wedge heavy(x) \wedge \exists e\, [carry(e) \wedge agent(e,peter) \wedge theme(e,X)]]]]$

b. $\exists X\, [\forall x\, [x{\in}X \leftrightarrow book_0(x)] \wedge heavy^*(X) \wedge \exists e\, [carry(e) \wedge agent(e,peter) \wedge theme^*(e,X)]]$

[7] 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*.

Both (32a) and (33) are ambiguous in the way the predicate *heavy* is applied to its arguments. Upon the predicate view of adjectives corresponding to (32d, e) 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 which introduces 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 Boston office called.
b. $office(x) \wedge boston(y) \wedge NN(x,y)$

Possessive expressions have in common with noun-noun modification that they introduce a relation that is not made explicit or that is expressed in a vague way using the preposition "of" in English and similarly vague prepositions in other languages (e.g. "de" in Romance languages, "van" in Dutch). Typical examples are shown in (40). What all these (and other) forms have in common is that they express some sort of possession relation between a (set of) possessor(s) and a set of possessions. Possessive expressions involve quantification over possessions (and possibly also over possessors). Similar to (39), a case like (40a1) can be analysed schematically as in (40b), introducing a generic 'Poss' relation, following Peters and Westerståhl (2013).

(40) a. 1. Tom's house
2. John and Mary's two children
3. two of my books
4. the headmaster's children's toys
5. the children of the headmaster

6. every student's library card

b. house(x) $\wedge$ tom(y) $\wedge$ Poss(x,y)

Modification by PPs bears some semantic similarity to noun-noun modification in the case of simple PPs, as the similarity of the representations (39b) and (41b) illustrates; 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.

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

b. book(x) $\wedge$ hongkong(y) $\wedge$ 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 the sentence *"Bell peppers for fifty pesos",* which was seen in a price tag of a box of bell peppers. This sentence 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-member(x) $\wedge$ from(x,y) $\wedge$ meet(kay,x)]]

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

If the sentence with the PP-modified NP 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 Iowa"*) contains an existentially quantified embedded NP (*"a small town in Iowa"*) 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 Iowa.

b. $\exists$y [iowa-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.[8]

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. Conjunctions in combination with adjectives and other modifiers moreover give rise to scope issues, 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

Studies of quantification in natural language have often 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 sonatas".* 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 milk", is syntactically very similar to the count noun case, but semantically different; compare the two sentences in (48):

(48) a. The boys polished all the knives in the drawer.

[8] 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.

b. The boys drank all the milk 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 (or 'portions') of milk. A difference is that (48a) can be analysed as: "Every knife in the drawer was the object in an polish-event with one of the boys as the agent", but it is not clear that the analogous analysis "Every quantity of milk 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 milk in the fridge includes glasses of milk, sips of milk, bottles of milk and, other quantities that were not as such the object of a drink-event. . A universal mass noun quantification of the form *"all the M"* does not refer to *all* the quantities of M, but rather to a certain subset of quantities that together make up the whole of "the M". (A similar situation arises 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 two 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?"*. A detailed analysis of mass noun quantification can be found in Bunt (1985), which combines elements from lattice theory and set theory in an integrated fashion. Quantities are analysed as having a part-whole structure, defining a sum operation Σ such that the sum of two quantities of M forms another quantity of M (similar to the operator in (18)). An expression of the form *"all the M"* with a mass noun *"M"*, is interpreted as referring to a set X of quantities of M that together make up the reference domain M_0 (i.e. the set of all contextually relevant quantities of M), in the sense that their sum equals the sum of all quantities in the reference domain: $\Sigma(X) = \Sigma(M_0)$.

Quantification with 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 'parts'. 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; sentence (49d) can be considered to be ambiguous between such a reading and a collective 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.[9] 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

[9] 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).

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 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 as ‘whole’. This is summarized in Table 1 below.

involvement	*distribution*	*interpretation*	*example*
all	parts	For every quantity of M	(49a)
total	parts	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’ or ‘meter/second’. Formally, a unit is either a basic unit or a triple $<u_1, u_2, Q>$ 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 specifies the information in annotations in terms of set-theoretical structures such as pairs and triples. A concrete syntax specifies a representation format for such structures, such as the XML format used in (19), where a triple $\langle e_1, e_2, R_i\rangle$ is represented by a sequence of XML elements, of which <srLink event="#e1" participant="#x1" semRole="agent"/> represents the agent relation, the event structure (e_1), and the participant entity structure.

A representation format for annotation structures should ideally give an exact expression of the information contained in such structures. A concrete syntax that defines 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 size and frequency specifications.

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 individual 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;

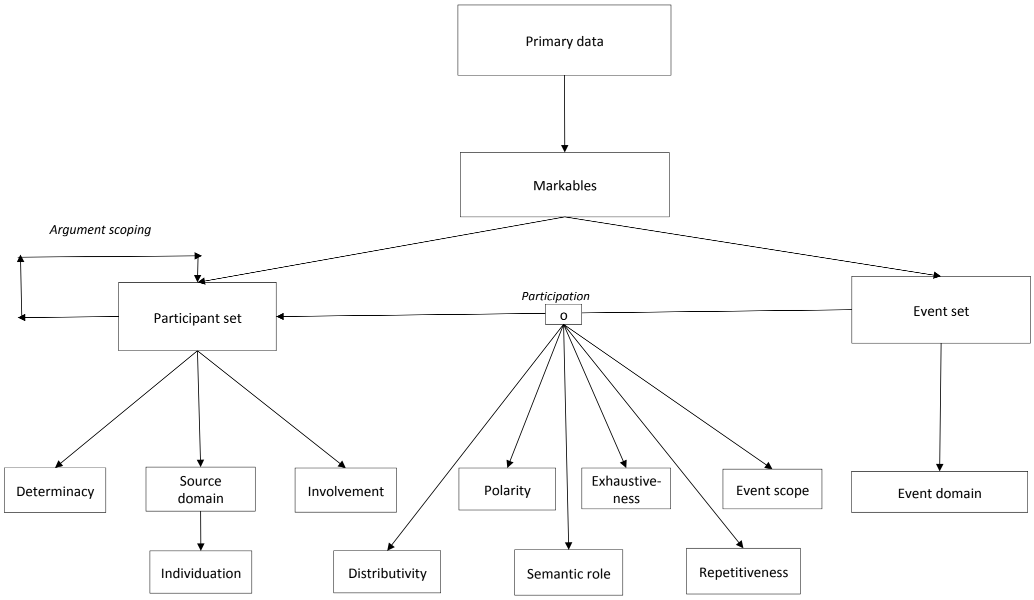

Figure 1: Metamodel for the annotation of quantification

3. the determinacy, 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 exhaustiveness of the quantification;
7. the size of the reference domain, or of groups, subsets, or parts of the reference domain involved in the quantifying predication;
8. the repetitiveness of recurring events (as in *"John called home twice every day"*).

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 $\langle e_1, e_2, R_i \rangle$ 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 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 $\langle m, s \rangle$ for a set of participants thus contains minimally a triple:

(53) $\varepsilon_p = \langle m, \langle S, q, d \rangle\rangle$

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

Cardinal determiners 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), the involvement (q), and the size specification (N) may have a complex internal structure. 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 are a numerical predicate, such as $\lambda z.\ |z| > 5$, or a measure predicate such as $\lambda z.\ \mathrm{Weight}(z) > (5, \mathrm{kilo})$. The involvement specification q may also be a proportional predicate, such as 'most of'. Since the components q and N are different for a mass NP quantifier than when the NP concerns a countable domain, therefore the component S 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). The component d (definiteness) is an unstructured value, viz. ‘determinate’ or ‘indeterminate’.

Proper names like *“Santa”* or *“ Donald Duck”* are treated not as quantifiers but as expressions that refer to a single individual. This applies also to a very 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 necessarily unique in an absolute sense, but who is uniquely determined in the given context by his salience, familiarity, or recent mention.

Entity structures ⟨m, ε_{EV}⟩ for sets of events are simpler than those for sets of participants; they contain besides a markable just a predicate that characterizes an event domain, which is a class of events, analogous to the source domain of a set of participants.

(55) ε_{EV} = ⟨m,event domain⟩

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 specifying a semantic role, a distributivity, whether the quantification over events has wide or narrow scope, whether the quantification is exhaustive, the repetitiveness (if any) of the participation, and a polarity. Scope link structures (56b) indicate a scope relation between two participant entity structures.

(56) a. L_P = ⟨ε_{EV}, ε_p, semantic role, distributivity, event scope, exhaustiveness, repetitiveness, polarity⟩
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 (46). 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⟩, 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 (46h). 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 2.6 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.

NP head noun	*distribution*	*link inversion*	*modifier category*

count, mass	Individual, parts	no	ADJ, NN, GP, PP, RC
count, mass	Individual, parts	yes	GP, PP, RC
count, mass	collective	no	ADJ, GP, PP, RC
count	unspecific	no	GP, RC, PP

Table 2. Types of NP head modification. GP = Genitive possessive structure.

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. The modification of an NP head noun is annotated with link structures that are embedded within NP annotation structures (i.e., participant structures), and therefore do not need to specify the entity that they link the modifier information to.

Noun-noun (NN) modification of a count noun always has individual distribution, and of a mass noun always has parts distribution, so the distribution in a NN-modification does not need to be annotated. A modifying noun may itself by modified, as in *"chemical waste dump"* (to be contrasted with *"old waste dump"*), or or by another noun, as in *"corona virus infections"*. So in NN-modification the modifying information consists of the property expressed by the modifying noun, combined with the information in any restrictions that may modify that noun. Inverse linking does not arise in this case, therefore the link structure for NN-modification is a pair consisting of a unary predicate, possibly with (adjectival or NN) restrictions:

(57) $L_{NN} = \langle$property, restrictions$\rangle$

Adjectives can be used distributively or collectively (as in *"Ken was carrying some heavy books"*). An adjective that modifies a noun that modifies another noun is treated in this document as introducing a complex concept, such as 'toxic waste' or 'natural language'. Adverbial modification of adjectives (e.g. *"very beautiful", "too expensive", "more expensive than expected*",...} } is considered to be outside the scope of the standard specified in this document. A link structure for adjectival modification is therefore a pair consisting of a unary predicate and a distributivity:

(58) $L_{AD} = \langle$property, distributivity$\rangle$

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 scheme specified in this document.

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

(59) $L_{PP} = \langle$relation, ε_P (participant structure), distributivity, linking$\rangle$

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 link structure for a relative clause is thus:

(60) $L_{RC} = \langle$annotation structure, semantic role, distributivity, linking$\rangle$

3.3.5 Formal specification

As mentioned above, the abstract syntax of QuantML 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. Such annotation structures are quadruples, consisting of an event structure, a non-empty set of participant structures, a set of link structures that relate participants to events, and a set of link structures that specify scope relations between sets of participants; see (62).

(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:

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, d is a definiteness, and N is a size specification (see below). 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 set to "single" and the definiteness to "determinate". A specification of reference domain involvement is either (1) a proportional predicate ('most', 'all', 'total', 'single', a percentage or a fraction), or (2) a non-numerical quantitative predicate (like 'many', see below), or (3) a numerical size specification (see auxiliary structures below).
2. Event structures: s is a predicate denoting an event domain.
3. Modifier structures:
   a. Adjectival structure: s = ⟨property⟩;
   b. Modifying nominal 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>;
   e. Possessive structure: s = ⟨Poss, participant structure⟩.

Auxiliary structures:

1. A domain specification structure is a nested pair DS = ⟨m,S⟩, where m is a markable and S is a domain structure. A domain structure is either a pair ⟨P,v⟩, consisting of a predicate P and an individuation specification v, or a sequence $\langle DS_1, \ldots DS_k\rangle$, of domain specification structures, or a pair ⟨DS, M⟩, where DS is a domain specification structure and M is a modification or a sequence of modifications . (see next item).
2. A modification is a structure for noun-noun modification, adjectival modification, or modification by a PP or a relative clause, i.e., it is either a pair ⟨predicate, restrictions⟩, or a pair ⟨adjectival structure, distribution⟩, or a triple ⟨PP structure, distribution, linking⟩, or a triple ⟨relative clause structure, distribution, linking⟩, or a triple ⟨possessive structure, distribution, linking⟩.

3. A numerical size specification, which can be used to indicate a reference domain involvement, the size of a reference domain, the size of groups of reference domain elements, or the repetitiveness of a set of events, is either (a) a pair ⟨r, n⟩, where ‘n’ is a positive (real) number, a percentage (like’5%’), or a fraction (like ’‘2/3’), and ‘r’ is one of the numerical relations ‘equal’, ‘greater than’, ‘greater than or equal’, ‘less than’, ‘less than or equal’, or (b) a nested pair ⟨r, ⟨n, u⟩⟩ with ‘r’ and ‘n’ as before, and ‘u’ either a basic unit of measurement or a unit structure. A unit structure is a triple $\langle u_1, op, u_2 \rangle$, where ‘$u_1$‘ and ‘$u_2$‘ are either a basic unit or a unit structure, and ‘op’ is either the operation of multiplication or that of division.

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

1. Participation links: A full link structure is a septet or an octet: ⟨event structure, participant structure, semantic role, distributivity, exhaustiveness, [repetitiveness or frequency of repeated participation], event scope, polarity⟩. To simplify the specification of participation links in annotation structure, the following values will often be suppressed: exhaustiveness = ‘non-exhaustive’, event scope = ‘narrow’, polarity = ‘positive’.
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 correspond to the meanings of lexical items (in particular NP head nouns) of the language of the primary data, such as ‘book’, ‘student’, and ‘water’;
2. predicates that characterize an event domain, corresponding to the meanings of verbs and other lexical items of the language of the primary data, such as ‘lift’, ‘carry’, ‘read’, ‘see’, ‘meet’;
3. predicates corresponding to the meanings of 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 meanings of prepositions in PPs, 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. predicates for specifying proportional reference domain involvement, such as “most”, “all”, “some” (for count NPs),),“single” for (singular) proper names and singular definite descriptions; “half”; and for mass NPs: “total”, “whole”, “some-m”, and “most-m”;
7. non-numerical predicates for specifying reference domain involvement, reference domain size, or the size of certain parts of a reference domain, corresponding to the meanings of lexical items like “many”, “much”, “several”, “few”, and “(a) little”;
8. parameters for specifying definiteness (in participant structures): “determinate” and “indeterminate”
9. basic units of measurement, such as ‘meter’, ‘kilogram’, ‘litre’, and ‘hour’ – see ISO 24617-6 (Principles of semantic annotation), Hao et al. (2017), and ISO DIS 24617-11; 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 ‘narrow-negative and `wide-negative’’ for specifying a polarity;
12. parameters for specifying distribution: ‘collective’, ‘individual’, ‘parts, ‘single’, ‘unspecific’;
13. parameters for specifying individuation: ‘count’, ‘mass’, and ‘‘count’/parts’;
14. parameters for specifying exhaustiveness: ‘exhaustive’, ‘non-exhaustive’;
15. parameters for specifying event scope: ‘wide’, ‘narrow’, and ‘free’;
16. ordering relations for specifying relative scopes of sets of participants (in participant scope links): ‘wider’, ‘equal’, ‘dual’, and ‘unscoped’;

17. 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. <entity>, for representing participant structures, has the attributes @domain, @involvement, @definiteness and (optionally) @size;
2. <event>, for representing event structures, has the attribute @pred for specifying an event type;
3. <qDomain>, for representing domain specification structures: has the attributes @source (with multiple values in the case of a conjunctive specification) and @restrictions;
4. <sourceDomain>, for representing quantification source domain specifications without modifiers, has the attributes @pred and @individuation;
5. <adjMod>, for representing adjectival modifiers, has the attributes @pred and @distr, and optionally the attribute @restrictions;
6. <nnMod>, for representing nouns as modifiers, has the attributes @pred and @distr, and optionally @restrictions;
7. <ppMod>, for representing PP modifiers, has the attributes @pRel, @pEntity, @distr and @linking;
8. <relClause> for representing relative clauses, has the attributes @semRole, @clause, @distr and @linking;
9. <possRestr>, for representing possessive restrictions, has the attributes @possessor, @distr, and @linking;
10. <numericalPred> has the attributes @numRel (with values like ‘greater than’, and @num (which has nonnegative numbers, percentages, and fractions as its possible val
11. <amount> has the attributes @num, and @unit;
12. <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, @rep (optional, default value: greater than or equal to 1), @exhaustiveness (default value: “non-exhaustive”, abbreviated “nex”), @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 identified by the corresponding markables in the annotated data. These values can be obtained by means of morphological preprocessing and lexical lookup (possibly supported by word sense disambiguation) of the content of the markables. In the example annotations in this document, such semantic values are represented by canonical forms of the lexical items of the language of the primary data, such as 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 'Lx(m)' to designate the lexical content of the markable 'm', and 'CF_{L1}' to designate a function that delivers canonical forms of (disambiguated) lexical items for the language 'L1', the values of the three occurrences of the @pred attribute in example (63) below are CF_{EN}(Lx(m5)) = "enroll", CF_{EN}(Lx(m3)) = "student", CF_{FR}(Lx(m3)) = "étudiant", and CF_{EN}(m2) = "chinese"; for better readability of QuantML/XML annotations such values are shown rather than "CF_{L1}(Lx(m5))" etc. (For convenience, the same values are also used in the abstract syntax.) (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 values of general linguistic significance, not restricted to English or another particular language.

3.5 Semantics: Outline

3.5.1 Overview

QuantML annotations have a compositional semantic interpretation, in the sense that the interpretation of an annotation structure is computed by combining the interpretations of its component entity structures and participation link structures, in a manner that is determined by its scope link structures. The specification of this semantics takes the form of translating annotation structures to (possibly underspecified) DRSs, whose interpretation is defined by Discourse Representation Theory (DRT, Kamp & Reyle, 1993). Combining GQT with neo-Davidsonian event semantics, natural language quantifiers are interpreted as properties of sets of participants involved in sets of events. Champollion (2015) has shown the viability of this type of combination. Casting the semantics in this form is particularly convenient for combining annotations of quantification with other types of semantic information, using annotation schemes of the ISO Semantic Annotation Framework (SemAF, ISO 24617). This section gives a brief overview of the semantics; more details are provided in Appendix B.

The natural unit for quantification annotation is formed by the specification of a set of events and the sets of participants involved. In linguistic terms , this unit typically corresponds to a (simple) clause: a verb with its arguments. The annotation of such a unit has the structure shown in (62). It consists of (1) an event structure, (2) a number of participant structures, (3) participation link structures that relate the participants to the events, and (4) scope relations among the participants. The first three components provide the building blocks of the semantic content of the annotation, while the scope relations determine the way these building blocks combine to provide an interpretation of the clause as a whole.

Participant entity structures correspond to semantic entities that may be of any kind: real-world objects, abstract entities, individual concepts, intentional and intensional entities, hypothetical and fictional entities. The annotation scheme defined in this document aims to be neutral with respect to ontological and linguistic views on the existence of objects of various kinds and the necessity to distinguish them in semantic accounts of natural language.[10]

A participation link structure has the form shown in (66), where the first two components are the linked event and participant structures, and the other components indicate properties of the way in which the participants are involved in the events, specifying a semantic role (R), a distributivity (d), whether the event quantification has wide or narrow scope ('event scope', σ), an exhaustiveness (ξ), a repetitiveness of repeated participation

[10] Moltmann (2015): "Whether natural language permits quantification over 'nonexistent' intentional objects is subject of a major controversy, as is the nature of such entities themselves". Szabolcsi (2012) notes that "many but not all important issues in noun phrase quantification can be addressed in a purely extensional semantics".

([ρ], optional) , and a polarity. For increased readability, the default values σ = 'narrow', ξ='non-exhaustive' and p='positive' will mostly be suppressed.

(66) $L_P = \langle \varepsilon_E, \varepsilon_P, R, d, \sigma, \xi, [\rho], p \rangle$

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

The semantics of a participation link structure is compositionally defined as a combination of the semantics of its components by means of the interpretation function I_Q, as specified in (67), where '$\cup$' is the operation of merging two DRSs, as defined in DRT, and '$\cup^*$' is the 'scoped merge' operation, defined in (76) below. For the most common case, where there is no repetitiveness component ρ, and where ξ='non-exhaustive' and p='positive', the interpretation function I_Q is defined by (67).

(67) a. $I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, \text{narrow}, p\rangle) = (I_Q(\varepsilon_P) \cup^* I_Q(\varepsilon_E)) \cup I_Q\,(R, d, \text{narrow}, p)$

b. $I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, \text{wide}, p\rangle) = (I_Q(\varepsilon_E) \cup^* I_Q(\varepsilon_P)) \cup I_Q\,(R, d, \text{wide}, p)$

c. $I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, \text{free}, p\rangle) = I_Q(\varepsilon_E) \cup I_Q(\varepsilon_P) \cup I_Q\,(R, d, \text{free}, p)$

For example, consider the sentence *"More than two thousand students protested"*, containing a verb with a single argument, so that the annotation structure contains just a single link structure. A quantifier of the form "*More than two thousand D"* is interpreted as a DRS of the form (68), 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 subset of the quantification domain D containing more than two thousand elements. This subset consists of those elements of the reference domain that participate in a set of events (called the 'participant set' in the QuantML metamodel, see Fig. 1). The condition $|X| > 2000$ specifies the involvement of the reference domain.

(68)
$$\begin{array}{|l|}\hline X \\ \hline |X| > 2000 \\ x \in X \;\rightarrow\; D(x) \\ \\ \hline\end{array}$$

A definite NP is interpreted as expressing that the entire reference domain is involved in a (quantified) predication. Using, as before, the notation 'D_0' to designate the predicate D restricted to the reference domain, this interpretation looks in DRS-form as shown in (69) for a quantifier of the form *"The three D"*.

(69)
$$\begin{array}{|l|}\hline X \\ \hline |D_0| = 3 \\ x \in X \leftrightarrow D_0(x) \\ \\ \hline\end{array}$$

For the sake of compactness, instead of the box notation of DRT also a string notation will be used, with square brackets instead of boxes, and a vertical bar to separate the list of discourse referents from the conditions. E.g., (68a) in this notation is: $[\, X \mid |X|>5000,\; x \in X \rightarrow D(x)\,]$ or also $[\, X \subseteq D \mid |X|>5000]$.

If R = Agent, d = individual, and the event scope is narrow, then the interpretation of the third component in (67) is the DRS in the right-hand side of (70), which says that there is a non-empty participant set of which every member is an agent in a non-empty set of events:

(70) $I_Q(\text{Agent,individual,narrow}) = [\, X \mid\mid x \in X \rightarrow [\, E \mid e \in E \rightarrow \text{agent}(e,x)\,]]$

Merging this participation structure interpretation with the DRSs interpreting the participant structure (71) and the event structure (72) results in the interpretation (73) for the sentence.

(71) $I_Q(\varepsilon_P) = [\, X \mid |X| > 2000,\ x \in X \rightarrow \text{student}(x)\,]$

(72) $I_Q(\varepsilon_E) = [\, E \mid e \in E \rightarrow \text{protest}(e)\,]$

(73) $[\, X \mid |X| > 2000,\ x \in X \rightarrow [\, E \mid e \in E \rightarrow [\ \mid \text{protest}(e), \text{agent}(e,x)\ \ \text{student}(x)\,]]]$

For a verb with multiple arguments in different semantic roles, the interpretations of the link structures are combined in a way that reflects the relative scoping of the arguments. If the quantification in one argument outscopes the quantification in another, then the combination is performed not by simple DRS-merge, but by a more complex operation called 'scoped merge'. This is illustrated by the analysis of sentence (74a) for the wide-scope reading of *"Fifteen students".* The annotation structure in (74c) contains two participant structures, two link structures and one scoping relation. The semantics is constructed by (75), where $\cup^*$ is the scoped merge operation, defined in (76).

(74) a. Fifteen students read three papers.

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

c. *QuantML annotation representation:*
<entity xml:id="x1" target="#m1" domain="#x2" involvement="15" definiteness="indet'"/>
<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="indet"/>
<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="wider"/>

d. *Annotation structure:*
⟨⟨ m3, read⟩, {⟨m1, ⟨⟨{⟨m2,student⟩, 15, indet⟩, ⟨m4, ⟨⟨⟨m5,paper⟩⟩, 3, indet⟩},
{⟨⟨m3, read⟩, ⟨m1, ⟨⟨{⟨m2,student⟩, 15, indet⟩, agent, individual, narrow⟩,
⟨⟨m3, read⟩, ⟨m4, ⟨⟨{⟨m5,paper⟩, 3, indet⟩, theme, individual, narrow⟩},
{⟨⟨m1, ⟨⟨{⟨m2,student⟩, 15, indet⟩, ⟨m4, ⟨⟨{⟨m5,paper⟩, 3, indet⟩}, wider⟩}⟩

e. *Semantic interpretation:*

(75) $I_Q(A) = I_Q(\langle \varepsilon_E, \{\varepsilon_{P1},\varepsilon_{P2}\}, \{L_{E,P1}, L_{E,P2}\}, \langle \varepsilon_{P1},\varepsilon_{P2},\text{wide}\rangle\}\rangle) = I_Q(L_{E,P1}) \cup^* I_Q(L_{E,P2})$.

The scoped merge operation is designed to combine the information about quantified participation in two participation link structures, and is defined as follows:

(76) *The scoped merge operation combines the information in its argument DRSs into a DRS that reflects the relative scoping of the quantifications involved, as well as the relative scopings of participants and events, while unifying the event discourse referents in the two arguments*. (If this unification is not possible, then the operation fails.)

The DRSs representing the semantics of such structures can have a limited variety of forms, listed in Annex B. Two of the most common forms are shown in (79a) and (80a), and more schematically in (79b) and (80b); they correspond to the interpretation of a participation link structure with narrow event scope and with individual and collective distributivity, respectively. C_{ij} designates a set of conditions, R_i a semantic role, and K_i a sub-DRS. Mass NP quantification with parts distribution has the same semantic representation as (79). For a quantification with wide event scope, everything else being the same, the semantics is like (79) but with the roles of the participant set (X) and the event set (E) interchanged.

(79) a. $A_i = [X_i \subseteq D_i \mid C_{i1}, x \in X_i \rightarrow [E_i \subseteq D_{Ei} \mid C_{i2}, e \in E \rightarrow R_i(e,x)$

b. A_i = = $[X_i \subseteq D_i \mid C_{i1}, x \in X_i \rightarrow K_i]$

(80) a. $A_i = [X_i \subseteq D_i, E_i \subseteq D_{Ei} \mid C_{i1}, e_i \in E_i \rightarrow R_i(e,X_i)]$
b. $A_i = [X_i \subseteq D_i, E_i \subseteq D_{Ei} \mid C_{i1}, K_i]$

The scoped merge of two arguments A_1 and A_2 of the form (79) brings the quantification over the participant set in the second argument within the scope of the one over the participant set in the first argument, as shown schematically in (81a) and in more details in (81b), where 'E' designates the unification of E_1 and E_2 - which is possible (only) because A_1 and A_2 are about the same events.

(81) a. $A_1 \cup^* A_2 = [X_1 \subseteq D_1 \mid C_{11}, x_1 \in X_1 \rightarrow [X_2 \subseteq D_2 \mid C_2, x_2 \in X_2 \rightarrow K_1 \cup K_2]$

b. $A_1 \cup^* A_2 = [X_1 \subseteq D_1 \mid C_{11}, x_1 \in X_1 \rightarrow [X_2 \subseteq D_2 \mid C_2, x_2 \in X_2 \rightarrow [E \subseteq D_{Ei} \mid C_{i1}, e \in E \rightarrow$
$[R_1(e. x_1), R_2(e. x_2)]]]$

Applied to the two link structures of (77), the right-hand side of (81b) is instantiated as (82).

(82) $[X_1 \subseteq \text{student} \mid |X_1|=15, x_1 \in X_1 \rightarrow [X_2 \subseteq \text{paper} \mid |Y|=3, x_2 \in X_2 \rightarrow [E \subseteq \text{read} \mid e \in E \rightarrow$
$[\text{agent}(e. x_1), \text{theme}(e. x_2)]]]$

Note that the scoped merge of two DRSs of the form (79) has again that same form; therefore scoped merge application may be repeated to deal with more than two arguments, leading to recursively nested quantifier interpretations.

The interpretation of participation link structures for non-quantifying NPs that refer to a single participant (proper names, definite descriptions, singular pronominal NPs) has the form (83), which is formally similar to (80), but where the discourse referent 'z' ranges over individuals.

(83) $A = [z, E \subseteq D_{Ei} \mid C_1, e \in E \rightarrow K_3]$

Because of this formal similarity, such interpretations can be combined with those of quantifying NPs using the scoped merge operation. The combination of participation link structure interpretations is discussed in more detail in Annex B.

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 (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 DRT as an 'underspecified DRS' (UDRS, Reyle, 1994).

Annex B specifies the semantics of QuantML annotation structures in more detail, including annotation of quantifications with negative polarity, with parts of individuals and parts of mass objects, of cumulative quantification, and quantifications with structured reference domains, and various kinds of modifiers (adjectives, nominals , PPs, relative clauses, possessives), including modifiers with inverse linking.

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Appendix A. Annotation guidelines and examples

A.1 Overview

Quantification in natural language occurs when a predicate is combined with one or more sets of arguments. This happens when a simple clause is formed by combining a verb with (plural) arguments, when a noun phrase (NP) is formed in which a (plural or mass) head noun is combined with adjectives or other modifiers, and when a verb or clause is modified by a quantifying adverb. The annotation of quantification is thus relevant at the level of clauses and at the clause-internal level of noun phrases.

QuantML is a triple-layered annotation scheme, with a concrete syntax, an abstract syntax, and a semantics. In the formal definition of the scheme, these layers are connected by three functions: (1) an encoding function F_{AC} that assigns to every well-formed structure of the abstract syntax one or more representation of the concrete syntax; (2) a decoding function F_{CA} that assigns to every structure of the concrete syntax a unique structure of the abstract syntax; (3) an interpretation function I_Q that assigns to every well-formed structure of the abstract syntax a semantic interpretation. Annotators only work with the concrete syntax; they can rely on the existence of the functions F_{CA} and I_Q for computing the semantics of their annotations. The guidelines in this annex apply to the QuantML/XML representation format.

A.2 Noun phrases

Following the Theory of Generalized Quantifiers, noun phrases (NPs) are viewed as denoting properties or families of sets of entities. This is true not only of plural NPs but also true singular NPs, like *"a present"* in example (4) in this document: *"Santa gave the children a present"*. NPs are annotated in QuantML with the <entity> tag, with values for its attributes chosen according to the following guidelines.

@domain: If the NP head is a bare common noun, then assign to this attribute as value the identifier of a <sourceDomain> element; the latter has the attribute @individuation, which specifies whether the noun is used as a mass noun or as a count noun, and in the latter case whether parts of the individuals in this domain are considered (if so, @individuation should be given the value "cParts"), and the attribute @pred, whose value is the characteristic predicate of the domain:[11]

<entity xml:id="x1" target="#m1" domain="#x2" involvement=… definiteness=…/>
<sourceDomain xml:id="x2" target="m2" individuation=… pred="[noun]"/>

If the NP is a (singular) proper name, then the same construction should be used, as follows:

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

If the NP head has modifiers, then assign to the @domain attribute as value a variable that identifies a <qDomain> element, which has an attribute @restrictions whose values indicate modifiers (see below, section A3), and a @domain attribute whose value 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=…/>

@involvement: If the NP contains a (pre-)determiner, such as *"all', "each", "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

[11] Formally, pred="Lx_{L1}(m2) ", i.e. the value of "pred" is computed from the markable that is the value of the @target attribute by the lexical lookup function Lx_{L1}, if L1 is the language of the source text (see 7.4.1).

“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 quantification by a mass NP, the three cases distinguished in Table 1 in Clause 6.8 should be marked up as having the involvement “all”, “total”, or “whole”.

For a singular definite description *(“the Christmas man”, “the president”),* or possessive *(“my mother”, “John’s birthday”)* the involvement should be specified as “single”.

@definiteness: This attribute should be assigned the value “indet” unless there is evidence that the NP quantifies over a particular, contextually determined part of the source domain defined by the NP head plus its modifiers. Such evidence may be the occurrence of a definite article, a possessive, or a demonstrative. Proper names are also understood as definite: the use of a name such as “John” carries the assumption that there is one contextually distinguished person named “John”. (See also Clause 6.3 in the main document.)

@size: This attribute should be assigned a value only if the NP contains a numerical determiner that is not interpreted as expressing involvement.

A.3 NP head modifiers

Adjectives are annotated with <adjMod> elements, in which the @distr attribute should be assigned the value “individual” if the adjective applies to the individual members of the reference domain, and “collective” if it applies to these members together; the @pred attribute gets is value in the same way as NP head nouns.

Nouns as modifiers are annotated with <nnMod> elements, in which the @pred attribute gets is value in the same way as NP head nouns.

NP head modification by a prepositional phrases is annotated with <ppMod> elements, in which the @distr attribute should be assigned the value “individual” if the PP applies to the individual members of the reference domain, and “collective” if it applies to these members together; the @linking attribute should be assigned the value “inverse” if the quantification of the NP in the PP outscopes the quantification of the NP head, else it should get the value “linear”.

The @pred attribute gets is value in the same way as NP head nouns.

Possessive modifications are annotated with <possRestr> elements, in which the @distr attribute should be assigned the value “individual” if the possessive restriction applies to the individual members of the reference domain, and “collective” if it applies to these members together; the @linking attribute should be assigned the value “inverse” if the quantification of the NP that refers to the possessor outscopes the quantification of the NP head, else it should get the value “linear”.

Relative clauses are annotated with <relClause> elements, in which the @distr attribute should be assigned the value “individual” if the adjective applies to the individual members of the reference domain, and “collective” if it applies to these members together; the @pred attribute gets is value in the same way as NP head nouns; the @linking attribute should be assigned the value “inverse” if the relative clause contains a quantification that outscopes the quantification of the NP head, else it should get the value “linear”.

A.4 Verbs and predicate-argument structures

Verbs are annotated in QuantML using the entity tag <event>, with attributes @pred, whose value specifies an event type, such as “kiss”, “love”, and “cook”, and optionally @rep, whose value specifies a natural number or a range of natural numbers (for dealing with expressions like *“twice”, “more than three times”*). The @pred values are obtained in the same way as for NP head nouns.

A.5 Participation links

For the attributes in <participation> links, the following guidelines apply:

@semRole: assign one of the semantic roles defined in ISO 24617-4.

@distr: Does each of the members of the participant set participate in the events by him/her/itself? If yes, assign the value “individual”. Do they act together, or are they acted upon together? In that case assign the value “collective”. If some of them act (or are acted upon) together, and others by themselves, assign the value “unspecific”. For a proper name or definite description, use the value “single”. For a mass NP, use the value “parts” if some or all the parts of a mass noun denotation participate, and “collective” if the parts act (or are acted upon) together.

@evScope: A quantifying NP nearly always outscopes the quantification over events, therefore “narrow” is the default event scope - this value is assumed if no other value is specified. Assign the value “wide” only multiple participants participated in the same events in the same semantic role. If the entity structure annotates a proper name or a definite description, assign the value “free”.

A.6 Scope links

Use the scope relation “wider” if one of the related quantifications outscopes the other, taking @arg1 for the one with wider scope. Use “dual” only in the case of cumulative quantification (mutual outscoping). Use “equal” only for the case of 5 quantification; see example (B2). If one of the related entity structures (or both) annotates a proper name or a definite description, use “unscoped”.

A.7 QuantML/XML annotation examples

(A1) Santa gave the children a present

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

QuantML-XML annotation:

```
<entity xml:id=”x1” target=”#m1” domain=”#x2” involvement=”single” definiteness=“det”/>
<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=“det”/>
<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=”single” evScope=”free”/>
<participation event=”#e1” participant=”#x3” semRole=”beneficiary” distr=”individual”
        evScope=”narrow”/>
<participation event=”#e1” participant=”#x5” semRole=”theme” distr=”individual”/>
        evScope=”narrow”/>
<scoping arg1=”#x3” arg2=”#x1” scopeRel=”unscoped”/>
<scoping arg1=”#x3” arg2=”#x5” scopeRel=”wider”/>
```

(A2) Fifteen students read three papers.

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

Annotation:

```
<entity xml:id=”x1” target=”#m1” domain=”#x2” involvement=”15” definiteness=”indet’”/>
<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=”indet”/>
<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=”wider”/>
```

(A3) All the students read some of the papers twice.

Markables: m1=All the students, m2=students, m3=read, m4=some of the papers, m5=papers

QuantML-XML annotation:

```
<entity xml:id=”x1” target=”#m1” domain=”#x2” involvement=”all” definiteness=”det’”/>
<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=”some” definiteness=”det”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”paper”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”individual”
            evScope=”narrow” repetition=”2”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”individual”
            evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x2” scopeRel=”wider”/>
```

(A4) 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=”indet’”/>
<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”/>
```

(A5) 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=books, m10=Japanese, m11=paintings

QuantML Representation:

```
<entity xml:id=”x1” target=”#m1” domain=”#x1” involvement=”1” definiteness=”det’”/>
<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=”indet’”/>
<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=”#m11” 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=”single” evScope=”free”/>

(A6) “Three men moved both pianos”

On the collective agent reading for *“Three men*”, the individual reading for *“both pianos”,* and narrow scope of the move-events, the sentence is annotated as follows. Collectively interpreted NPS refer to a single collection of individuals, and are outscoped by all ‘real’ quantifiers.

Markables: m1=Three men, m2=men, m3=moved, m4=both pianos, m5=pianos

QuantML-XML annotation:
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”3” definiteness=“indet”/>
<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=”det”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”piano” indiv=”count”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”collective”/>
<participation event=”#e1” participant=”#x3” semRole=”patient” distr=”individual”
evScope=”narrow”/>
<scoping arg1=”#x2” arg2=”#x1” scopeRel=”wider”/>

(A7) Alex sold the two ancient books.

Markables: m1=Alex, m2=sold, m3=the two ancient books, m4=ancient books, m5=ancient, m6=books

QuantML-XML annotation:
<entity xml:id=”x1” target=”#m1” domain=”#x2” involvement=”single” definiteness=”det”/>
<sourceDomain xml:id=”x2” target=”#m1” pred=”alex”/>
<event xml:id=”e1” target=”#m2” pred=”sell”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”single” evScope=”free”/>
<entity xml:id=”x3” target=”#m3” domain=”#x4” involvement=”all” definiteness=”det’” size=”2”/>
<qDomain xml:id=”x4” target=”#m4” source=”#x5” restrictions=”#r1”/>
<sourceDomain xml:id=”x5” target=”#m6” individuation=”count” pred=”book”/>
<adjMod xml:id=”r1” target=”#m5” distr=”individual” pred=”ancient”/>
<scoping arg1=”#x3” arg2=”#x1” scopeRel=”wider”/>

(A8) 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=”all” definiteness=“det”/>
<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=“det”/>
<sourceDomain xml:id=”x5” target=”#m6” pred=”lake” indiv=”count”/>
<event xml:id=”e1” target=”#m7” pred=”polluted”/>
<participation event=”#e1” participant=”#x1” semRole=”theme” distr=”all” evScope=”narrow”/>

(A9) The boys drank all the beer.

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

QuantML-XML annotation:
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=“det”/>
<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=“det”/>
<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=“parts” evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”dual”/>
```

(A10) The crane lifted all the sand.

Markables: m1=the crane, m2= crane, m3=lifted, m4=all the sand, m5=sand

QuantML-XML annotation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=“det” 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=“det”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”sand” indiv=”mass”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”single” evScope=”free”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”collective” evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”equal”/>
```

(A11) Three breweries supplied fifteen inns

Markables: m1=three breweries, m2= breweries, m3=supplied, m4=fifteen inns, m5=inns

QuantML-XML annotation:

```
<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=”dual”/>
```

(A12) The president did not accept the proposals

Markables: m1=the president, m2= president, m3=did not accept, m4= the proposals, m5=proposals

QuantML-XML annotation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”single” definiteness=“det”/>
<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=“det”/>
<sourceDomain xml:id=”x4” target=”#m5” pred=”proposal” indiv=”count”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”single” evScope=”free”
        polarity=”negative”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”individual” evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”wider”/>
```

(A13) Every man loves his mother

Markables: m1=every man, m2=man, m3=loves, m4=his mother, m5=his, m6=mother

QuantML-XML annotation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=“det”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”man” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”loves”/>
```

```
<entity xml:id="x3" #target="#m4" domain="#x4" involvement="single" definiteness="det"/>
<qDomain xml:id="x4" target="#m4" source="#x4" restrictions="#r1"/>
<sourceDomain xml:id="x4" target="#m6" pred="mother" indiv="count"/>
<possRestr xml:id="r1" target="#m5" source="#x4" possessor="#x1" distr="individual"/>
<participation event="#e1" participant="#x1" semRole="pivot" distr="individual" evScope="narrow"/>
<participation event="#e1" participant="#x3" semRole="theme" distr="individual" evScope="narrow"/>
 <scoping arg1="#x1" arg2="#x3" scopeRel="wider"/>
```

Appendix B. QuantML Semantics

The interpretation function I_Q, introduced in Section 3.5, specifies a recursive translation of QuantML annotation structures into DRSs. The recursion ends at the minimal building blocks of the annotation structures, which are elements of the QuantML conceptual inventory. These elements can be divided into two types: (i) 'structural' ones, that function as parameters in the specification of I_Q and determine structural properties of DRSs; and (ii) 'lexical' ones, that correspond to predicates or argument terms in DRS conditions. Elements of type (i) are for example definiteness values ('determinate', 'indeterminate') and event scope values ('wide', 'narrow'); their role as parameters in I_Q is described in Section B3. Elements of type (ii) are for example the predicates that express the semantics of nouns and verbs; their translation to DRS elements is specified by the assignment function F_Q, described in Section B2.

B1 'Lexical' conceptual inventory items

The assignment F_Q function for 'lexical' conceptual inventory items is defined as follows:

- Predicates that characterize quantification source domains or event domains (typically corresponding to nouns and verbs), and which in annotation representations are designated by canonical forms of lexical items of the language of the primary data, are semantically identical to predicates in DRS conditions. For such predicates $F_Q(P) = P$. Similarly for predicates that correspond to adjectives, expressing restrictions on quantification domains, or prepositions that express relations in PP modifications. The same is also true for predicates that designate semantic roles, which do not have an explicit basis in natural language words.

- Non-numerical quantitative specifications of domain involvement by means of expressions such *"a few"*, *"a little"*, *"several"*, *"many"* in English, and for example by *"beaucoup"*, *"quelques"*, *"plusieurs"*, in French and by *"een paar"*, *"een boel"*, *"ettelijke"* in Dutch, are one-place predicates. The interpretation of such predicates is context-dependent and language-specific. In QuantML annotations, predicates corresponding to words in the primary data are used for such specifications, as well as in their DRS-translations, leaving their precise interpretation to the interpretation of the DRS. For such predicates, again, $F_Q(P) = P$.

- The interpretation of a proportional specification of domain involvement, e.g. by 'most', depends on the reference domain, for example, *"most (of the) books are old"* is interpreted as saying that more than half of the books in the reference domain are old. The assignment function F_Q therefore assigns to the involvement specification 'most' the function $F_Q(\text{most}) = \lambda Z.\ \lambda X.|X|^* > (|Z_0|^*/2)$, which can be applied to a domain specification like 'book' to produce the predicate $\lambda X.|X| > (|book_0|/2)$, i.e. the predicate of having more elements than half the number of books in the reference domain (similarly for domains that include parts of individuals, as in *"most of the pizza"*). Fractional specifications, like *"two thirds of"* and percentual specifications, like *"twenty percent of"* are treated similarly, as are *"all"* and *"total"* for mass NP quantification: $F_Q(\text{all}) = \lambda Z.\lambda X.\ X=Z_0$, and $F_Q(\text{total}) = \lambda Z\ \lambda X.\ \Sigma X=\Sigma Z_0$. The involvement "most-m" of a mass NP quantification, as in *"Most of the milk was spilled"*, presupposes some way of measuring the size of quantities of a mass domain M. Such sizes are customarily measured using a certain domain-dependent dimension, for example, quantities of milk are typically measured in terms of volume, quantities of sugar in weight, and quantities of rope in length. The involvement "most-m" is therefore interpreted as F_Q(most-m) = $\lambda M.\lambda X.|\Sigma X|^M > (|\Sigma M_0|^M/2)$, where $|z|^M$ designates the size of z using the dimension that is normally used to measure quantities of M.

- Numerical predicates that are used to specify absolute domain involvement, reference domain size, or the size of certain parts of a reference domain, such as $\lambda n.\ n=2$ (abbreviated "2" in QuantML/XML) and $\lambda n.n>1$ (abbreviated ">1"), as well as ($\lambda n.n>500$, kilo) are also used in DRS conditions. The interpretation of such complex predicates is defined not by F_Q but by the recursive function I_Q, see (B1) below.

- The basic units of measurement, such as 'meter', 'kilo', 'litre', and 'hour', are used as terms in DRS conditions. For these elements $F_Q(u) = u$.

B2 Entity structures

B2.1 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 (count or mass or count with internal part-whole structure). In general, DS may contain a sequence of domain specifications and a sequence of modifiers:

$\langle\langle\langle S_1, S_2,\ldots S_k\rangle, \langle M_1, M_2,,\ldots M_n\rangle\rangle, q, d, N\rangle$

Domain specifications may in turn include a subsequence of domain specifications and local modifiers. For the annotation of the generalized quantifier expressed by an indeterminate NP, and 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 (B3). The predicate q' occurring in (B3)-(B8) is defined in (B1), viz. by composing $I_Q(q)$ with the interpretation $F_Q(v)$ of the individuation specification. If the quantification involves individuals and/or parts of individuals, then its involvement is measured in terms of number of individuals by adding up the sizes of participating parts expressed as fractions of individuals. This size, designated by $|..|^*$, differs from the cardinality of the participant set, unless the participant set happens to contain only entire individuals (in which case $|X|^* = |X|$). If q is a quantitative predicate in the form of an amount expression ⟨N,u⟩, then the unit ('u') in such a structure belongs to a certain dimension: a litre is a unit of volume, a kilo is a unit of weight, a meter a unit of length, and so on. The semantics of a unit term is therefore a pair $\langle D^u$, u'⟩, consisting of a dimension D and a unit u' as defined in that dimension (see Bunt, 1985), For example, the semantics of the unit in an expression like *"two litres of milk"* refers to the dimension 'volume' and a unit as a formal object in that dimension. In (B1), the subscripts '1', '2' indicate the first and second member of a pair.

(B1) $q' = \lambda z.\ I_Q(q)((F_Q(v))(z))$, where $F_Q(v)$ is defined as:
$F_Q(\text{count}) = \lambda X.|X|$; $F_Q(\text{count/parts}) = \lambda X.|X|^*$; $F_Q(\text{mass}) = \lambda X.\Sigma X$;
$I_Q(q)$ is defined as: $I_Q(q) = q$ if q is a numerical predicate;
$I_Q(q) = (F_Q(N(F_Q(u)_1(F_Q(v))(z)), F_Q(u)_2)$ if q is an amount expression ⟨N,u⟩, with numerical predicate N.

The domain predicates D', D'_0 , D_1', etc., occurring in ((B3) - (B9), are defined in (B2), see also (18) for the notation P^.

(B2) $D' = I_Q(D,v)$, with: $I_Q(D,\text{count}) = I_Q(D,\text{mass}) = F_Q(D)$; $I_Q(D,\text{count/parts}) = (F_Q(D))$^

For participant structures with an unstructured domain the interpretation is defined by (B3)-(B5). If the reference domain is a specific, contextually determined part of the source domain, then the participant structure is interpreted as in (B4), where D_0 designates the characteristic predicate of the reference domain related with the source domain D. In both (B3) and (B4) case a applies if the domain involvement specification (q_a) is absolute; case b if it is proportional (q_p).[12]

(B3) a. $I_Q(\langle D,v\rangle, q_a, \text{indet}) = [\ X \mid q_a'(X),\ x \in X \rightarrow D'(x)\ ]$

b. $I_Q(\langle D,v\rangle, q_p, \text{indet}) = [\ X \mid (q_p'(D'_0))(X),\ x \in X \rightarrow D'(x)\ ]$

(B4) a. $I_Q(\langle D,v\rangle, q_a, \text{det}) = [\ X \mid q_a'(X),\ x \in X \rightarrow D_0'(x)\ ]$

b. $I_Q(\langle D,v\rangle, q_p, \text{det}) = [\ X \mid (q_p'(D'_0))(X),\ x \in X \rightarrow D_0'(x)\ ]$

If the annotated NP contains a size specification ('N') of the reference domain, then the interpretation of the participant structure is as specified in (B5), again with case a for absolute involvement specification and case b for proportional specification:

(B5) a. $I_Q(\langle D,v\rangle, q_a, \text{det}, N) = [\ X \mid N'(|D'_0|),\ q_a'(X),\ x \in X \rightarrow D_0'(x)\ ]$

b. $I_Q(\langle D,v\rangle, q_p, \text{det}, N) = [\ X \mid N'(|D'_0|),\ (q_p'(D'_0))(X),\ x \in X \rightarrow D_0'(x)\ ]$

If v=count/parts then the domain predicates D and D_0, in (B3) - (B5) are replaced by D^ and D_0^.

A conjunctive NP head introduces a disjunctive condition. As in the case of simple domains, the interpretation of the entity structures depends on whether the involvement specification is absolute or proportional:

(B6) a. $I_Q(\langle\langle\langle D_1,v_1\rangle, \langle D_2,v_2\rangle, \ldots \langle D_k,v_k\rangle\rangle, q_a, \text{indet}\rangle) = [\ X \mid q_a'(X),\ x \in X \rightarrow [\ \mid D_1'(x) \vee D_2'(x) \ldots \vee D_k')x)]\ ]$

b. $I_Q(\langle\langle\langle D_1,v_1\rangle, \langle D_2,v_2\rangle, \ldots \langle D_k,v_k\rangle\rangle, q_p, \text{indet}\rangle) = [\ X \mid q_p'(D_{10}' \cup D_{20}' \cup \ldots \cup D_{k0}')(X),\ x \in X \rightarrow [\ \mid D_1'(x) \vee D_2'(x) \ldots \vee D_k'(x)]\ ]$

(B7) a. $I_Q(\langle\langle\langle D_1,v_1\rangle, \langle D_2,v_2\rangle, \ldots \langle D_k,v_k\rangle\rangle, q_a, \text{det}\rangle) = [\ X \mid q_a'(X),\ x \in X \leftrightarrow [\ \mid D_{10}'(x) \vee D_{20}'(x) \ldots \vee D_{k0}'(x)]\ ]$

b. $I_Q(\langle\langle\langle D_1,v_1\rangle, \langle D_2, v_1\rangle, .. \langle D_k,v_1\rangle\rangle, q_p, \text{det}\rangle) = [\ X \mid q_p'(D_{10}' \cup D_{20}' \cup \ldots \cup D_{k0}')(X),$
$x \in X \leftrightarrow [\ \mid D_{10}'(x) \vee D_{20}'(x) \ldots \vee D_{k0}'(x)]\ ]$

(B8) a. $I_Q(\langle\langle\langle D_1,v_1\rangle, \langle D_2,v_2\rangle, \ldots \langle D_k,v_k\rangle\rangle, q_a, \text{det}, N\rangle) =$
$[\ X \mid q_a'(X),\ N'(|D_{10}' \cup D_{20}' \cup \ldots \cup D_{k0}'|),\ x \in X \leftrightarrow [\ \mid D_{10}'(x) \vee D_{20}'(x) \ldots \vee D_{k0}'(x)]\ ]$

b.$I_Q(\langle\langle\langle D_1,v_1\rangle, \langle D_2,v_2\rangle,\ldots \langle D_k,v_k\rangle\rangle,, q_p, \text{det}, N\rangle) = [\ X \mid q_p'(D_{10}' \cup D_{20}' \cup \ldots \cup D_{k0}')(X),\ N'(|D_{10}' \cup D_{20}' \cup \ldots \cup D_{k0}'|),\ x \in X \leftrightarrow [\ \mid D_{10}'(x) \vee D_{20}'(x) \ldots \vee D_{k0}'(x)]\ ]$

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 restricted by adjectives, nouns, PPs, relative clauses or possessives. Restrictions come in four varieties as shown in Table 2. To show the semantics of the various types of modifications, the following specifications first describe the effect of a

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[12] In the string notation of DRSs some convenient and slef-explanatory shorthand notations will be used, such as $[\ X \subseteq P \mid C1\ ]$ for $[\ X \mid C1,\ x \in X \rightarrow P(x)\ ]$, $[\ X = P \mid C1\ ]$ for $[\ X \mid C1,\ x \in X \leftrightarrow P(x)\ ]$, and $[\ x \in P \mid C1\ ]$ for $[\ x \mid C1,\ P(x)\ ]$.

single restriction for a non-conjunctive NP head. This is subsequently generalized for multiple restrictions and conjunctive NP heads.

A restriction 'r' with individual or homogeneous distribution and linear linking introduces a condition in the embedded DRS as shown in (B9a), where D' is defined by (B2) and r' = I_Q(r):, defined in B.2.3.

(B9a) $I_Q(\langle\langle\langle D, \text{count}\rangle, \langle r\rangle\rangle, q, \text{indet}\rangle) =$
$I_Q(\langle\langle\langle D, \text{count}\rangle, \langle r, \text{individual}\rangle\rangle, q, \text{indet}\rangle) =$
$I_Q(\langle\langle\langle D, \text{count}\rangle, \langle r, \text{individual, linear}\rangle\rangle, q, \text{indet}\rangle) =$
$I_Q(\langle\langle\langle D, \text{count/parts}\rangle, \langle r, \text{individual, linear}\rangle\rangle, q, \text{indet}\rangle) =$
$I_Q(\langle\langle\langle D, \text{mass}\rangle, \langle r, \text{parts, linear}\rangle\rangle, q, \text{indet}\rangle) = [\ X \mid q'(X), x \in X \ \rightarrow (\ [\ \mid D'(x)] \cup r'(x))]$

Similarly for a modifier used with unspecific distribution and linear linking, but in this case the modifying predicate is generalized from being defined only for individuals to also being applicable to *sets of individuals* in the reference domain. This is expressed in (B9b), (Note that X* contains all the elements of X as well as all the subsets.)

(B9b) $I_Q(\langle\langle\langle D,\text{count}\rangle, \langle r,\text{unspec,linear}\rangle\rangle, q, \text{indet}\rangle) = [X \mid q'(X), x \in X^* \rightarrow (\ [\ \mid D'^*(x)\ ] \cup r'^*(x)\ )]$

For the non-collective 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 (B9c).

(B9c) $I_Q(\langle\langle\langle D,\text{mass}\rangle, \langle r,\text{parts ,linear}\rangle\rangle, q, \text{indet}\rangle) = [X \mid q'(\Sigma(X)), x \in X \ \rightarrow (\ [\ \mid D'(x)\ ] \cup r'(x)\ )\ ]$

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 (B9d).

(B9d) $I_Q(\langle\langle\langle D,\text{count/parts}\rangle, \langle r,\text{unspec,linear}\rangle\rangle, q, \text{indet}\rangle) = [X|q'(|X|^*), x \in X^\wedge \rightarrow ([|D'^\wedge(x)] \cup r'(x))]$

Regardless the individuation of the domain, a modification with collective distribution introduces, an additional condition at the DRS top level, as shown in (B9e), where 'v' can be any value:

(B9e) $I_Q(\langle\langle\langle D,v\rangle, \langle r, \text{collective, linear}\rangle\rangle, q, \text{indet}\rangle) = [\ X \mid q'(X), r'(X), x \in X \rightarrow \ D'^*(x)]$

The interpretation rules in (B9) all have a counterpart for the determinate case, like (B3) has the definite counterpart (B4), as well as a counterpart for the determinate case with size specification, like (B5).

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 (B10) the top-level quantification in the case of the (unlikely) interpretation with linear linking is shown in (B11).

(B10) Three students from every Dutch university participated.

(B11)

<table>
<tr><td colspan="2">X</td></tr>
<tr><td>|X|=3
x ∈ X →</td><td><table><tr><td>U</td></tr><tr><td>student(x)
u ∈ U ← [| dutch(u), university(u)]
u ∈ U → [| dutch(u), university(u), from(x,u)]</td></tr></table></td></tr>
</table>

To obtain the more plausible inversely linked reading, the two quantifications in this DRS are switched around, using the scope-switching operation defined in (B12), after first linking the top-level quantified participants to the event(s) under consideration, to get the result (B13).

(B12) $\quad \mathrm{InvScope}([X \mid C1, x \in X \rightarrow [Y \mid C2, y \in Y \rightarrow N]]) = [Y \mid C2, y \in Y \rightarrow [X \mid C1, x \in X \rightarrow N]]$

(B13)

$$\begin{array}{|ll|}\hline U & \\ \hline u \in U \leftarrow [\ \mid dutch(u), university(u)\ ] & \\ u \in U \rightarrow & \begin{array}{|l|}\hline X \\ \hline |X|=3, \\ x \in X \rightarrow student(x), [\ E \mid e \in E \rightarrow \\ \qquad\qquad [\ \mid participate(e), agent(e,x), from(x,u)\ ] \\ \hline \end{array} \\ \hline \end{array}$$

Modifications with inverse linking can be expressed by PPs, by possessive restrictions, and (marginally) by relative clauses. The semantic interpretation of PP and RC annotation structures is described below

Proper names and (singular) definite descriptions are usually viewed as referring expressions rather than quantifiers, and do not necessarily fall within the scope of quantification annotation, but it would seem rather awkward to for example include the treatment of plural expressions like *"the children"* but not of their singular counterpart *"the child".* The QuantML annotation scheme therefore does include a treatment of proper names and definite singular NPs, without going into the details of the presuppositions that may be associated with their use concerning uniqueness and existence (see e.g. Coppock and Beaver, 2015).

Entity structures for noun phrases consisting of a proper name are interpreted as introducing the single participant of a singleton set. For example, the proper name *"John Smith"* as the contextually distinguished individual who satisfies the condition $johnsmith_0(x)$, with the presupposition that there is only one such individual. This is expressed by the DRS $[\ x \mid johnsmith_0(x), \mid |johnsmith_0|=1\ ]$.

Similarly for definite descriptions like *"the chef",* interpreted as $[\ x \mid chef_0(x), \mid |chef_0|=1\ ]$.

B2.2 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 (B14):

(B14) $\quad I_Q(P_E) = [\ E \mid e \in E \rightarrow P_E(e)\ ]$

B2.3 Modifier structures and possessive restrictions

B2.3.1 Adjectives

Adjectives are one-place predicates, represented by names that correspond to lexical items of the language of the primary data. In order to use their semantics in composing the meanings of annotation structures in the same way as other adnominal modifiers (relative clauses, PPs, and nominal modifiers), the interpretation of an adjectival modifier structure is defined as a function which, applied to an argument (individual constant or bound variable), yields a DRS (cf. (B9a)).

(B17) $\quad I_Q(\langle\langle A, individual\rangle\rangle = \lambda z.\ [\ \mid A'(z)\ ]$

B2.3.2 Nouns as adnominal modifiers

The entity structure for a noun modifying another noun is a pair $\langle m, \langle N\rangle\rangle$ consisting of a markable and a property, or a structure $\langle m, \langle N, r_1,.., r_n\rangle\rangle$, $n\geq1$ where the property (N) is accompanied by a sequence of modifiers. The specification in (B18) 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).

(B18) a. $I_Q(\langle N\rangle) = \lambda z.$ [y | N'(y), NN(z,y)]
b. $I_Q(\langle N, r_1,.., r_n\rangle) = \lambda z.$ [y | N'(y), NN(z,y), r_1'(y),…, 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"*.

B2.3.3 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 $\varepsilon_{RC} = \langle m,s_{RC}\rangle$ annotating an RC has the form (B19), 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.

(B19) $s_{RC} = \langle R_a$ (semantic role), α_{RC} (annotation structure) $\rangle$

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 (B20):

(B20) $\alpha_{RC} = \langle \varepsilon_{EV}, \{\varepsilon_{P1},..., \varepsilon_{Pn}\}, \{L_{P1},..., L_{Pn}\}, \{sc_1,..., sc_k\}\rangle$

The interpretation of such an annotation structure, if it is fully scoped, has a sub-DRS (the *nucleus*) 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 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 this participant variable is abstracted over. This is expressed schematically in (B21), where 'IN(K,C)' designates the operation of inserting condition C in the nucleus of DRS K, 'evv(K)' designates the event variable of K, and α' abbreviates $I_Q(\alpha_{RC})$.[13]

(B21) $I_Q(R_a, \alpha_{RC}) = \lambda z.IN(\alpha', R_a'(evv(\alpha'), z))$

Predicates as defined in (B21) can be substituted for r_1' in (B9) 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.

B2.3.4 Prepositional phrases

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}. of a quantifying NP has the schematic form shown in (B22a), where C_1 and C_2 are sets of conditions; if the NP in the

[13] 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.

PP is not a quantifier, but a proper name (as in *"from Tokyo"*) or a (singular) definite description, then its interpretation has the form shown in (B22b).

(B22) a. $[\ X \mid C_1, x \in X \rightarrow [\ \mid C_2\ ]]$
b. $[\ x \mid C_1]$

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 embedded DRS in the quantifier case and to the main DRS in the non-quantifier case:

(B23) a. $\lambda z.\ [\ X \mid C_1, x \in X \rightarrow [\ \mid C_2, R_P'(x,z)\ ]]$
b. $\lambda z.\ [\ x \mid C_1, R_P'(x,z)\ ]$

The predicates in (B23) are constructed as specified in (B24). The operations 'INA_0' and 'INA_1', defined in (B25), take as input a DRS that interprets a quantified participant entity structure (case B23a)) or a non-quantified one (case (B23b)), corresponding to the NP in a PP, and a binary relation R_P', corresponding to a PP's preposition. This relation is used to form a DRS-condition by applying it to (1) the quantified discourse referent in ε_P' (case (B23a), the variable 'x') or to the top-level discourse referent in ε_P' (case (B23b), the variable 'x'), and (2) to a variable that is abstracted over. This condition is inserted in the embedded DRS in the quantified case and in the main DRS in the non-quantified case.

(B24) a. $I_Q(R_P, \varepsilon_P) = INA_1(\varepsilon_P', R_P')$
b. $I_Q(R_P, \varepsilon_P) = INA_0(\varepsilon_P', R_P')$

(B25) a. $INA_1([\ X \mid C_1(X), x \in X \rightarrow C_2\ ], \lambda u. \lambda v\ R(u,v)) = \lambda z. [X \mid C_1(X), x \in X \rightarrow C_2, \lambda u. \lambda v. R(v,u)(x)(z)\ ] =$
$= \lambda z. [X \mid C_1(X), x \in X \rightarrow C_2, R(x,z)\ ]$

b. $INA_0([\ x \mid C_1(x)\ ], \lambda u. \lambda v\ R(u,v)) = \lambda z. [\ x \mid C_1(x), \lambda u. \lambda v\ R(v,u)(x)(z)\ ] = \lambda z. [\ x \mid C_1(x), R(x,z)\ ]$

A one-place predicate built in this way can be substituted for r_1' in (B9) to form the DRS interpreting a linearly linked PP-modification, and via scope inversion to interpret an inversely linked PP-modification.

A postnominal possessive restriction, as in *"a desk of the UN Secretary-General"* is treated in the same way as a PP modifier, except that *"of "* is interpreted as the relation 'Poss'.

B2.3.5 Possessives

Prenominal possessive structures can be formed with possessive pronouns, as in (B26a), and with genitives, which in some languages may be quite complex and include quantifiers, as in (B26b,c), giving rise to issues of distributivity and inverse/linear linking. Semantically, possessive structures can be analysed in terms of a possessor, a possessee, and a binary relation 'Poss' between them (Peters and Westerståhl, 2013). In QuantML they are treated like prepositional phrases, except that the relation between the discourse referents of the modified NP and the possessor(s) is invariably the Poss relation.

(B26) a. Tom catalogued most of his boooks.
b. Two of every student's essays were lost
c. The headmaster's childrens' toys disappeared
d. Every scholar loves two of his books.

The possessive nominal *"his books"* in (B26a,d) is interpreted as referring to a set of books that are owned by somebody: $[\ Y \mid \ |y \in Y \rightarrow [\ z \mid book(y), Poss(z,y)]\ ]$. This 'somebody' will be instantiated by the possessor identified upon resolution of the anaphoric 'his'.

The interpretation of the annotation structure of (B26d) is obtained by the scoped merge of the NP annotation interpretations linked with a love-event in their respective semantic roles, while interpreting the anaphoric *"his"* as referring to a member of the participant set of the quantifier *"Every scholar"*. The operation that performs this scoped merge, designated by $\oplus^{as}$ ('anaphoric scoped merge'), is defined in (B27). Like the ordinary scoped merge, it merges the nuclear information in two participation structures while observing the scope relations between the quantifiers; additionally, the anaphoric element in the second argument is interpreted as the quantified referent provided in the first argument.[14] This operation, designated 'ANS' (Anaphoric Substitution), combines a condition C(z) with a referent a to produce the condition C(a) - see (B27a). In (B27e) the interpretation scheme specified in (B28a-d) is instantiated for the annotation structure of sentence (B26d).

(B27) a. $ANS([\ z \mid C(z)\ ], a) = C(a)$

b. $Arg1 = [\ X \mid C_1, x \in X \rightarrow K_1\ ]$

c. $Arg2 = [\ Y \mid C_2, y \in Y \rightarrow [\ z \mid Poss(z,y)\ ], y \in Y \rightarrow K_2]$

d. $Arg_1 \oplus^{as} Arg_2 =_D [\ X \mid C_1, x \in X \rightarrow K_1\ ] \oplus^{s} (Y \mid C_2, y \in Y \rightarrow ANS([\ z \mid Poss(z,y)\ ], x), y \in Y \rightarrow K_2]$

e. $I_Q(\alpha) = I_Q(L_{P1}) \oplus^{ps} I_Q(L_{P2}) = [\ X \mid x \in X \rightarrow [\ scholar(x), [\ Y \mid |Y|=2, y \in Y \rightarrow book(y), Poss(x,y),$
$y \in Y \rightarrow [\ E \mid e \in E \rightarrow love(e), pivot(e,x), theme(e,y)]]]\ ]$

The examples b and c show a quantifying possessive construction, inversely linked to its NP head, assuming that these sentences should be interpreted as "For every student, two of his/her essays were lost" and "Of every one of the headmaster's children the toys disappeared", respectively.

A postnominal possessive restriction, as in *"The desk of the UN Secretary-General"* is treated in the same way as other PP modifications, except that the preposition *"of "* is interpreted as the relation 'Poss'.

B3 Link structures

B3.1 Participation links

B3.1.1 Links with positive polarity

As specified in (67) in Section 3.5.1, the interpretation of a participation link structure with positive polarity is formed by the DRS-merge of the interpretations of (1) the participant structure, (2) the event structure, and (3) the link structure, which is a quintet or a sextet $\langle R, d, s, \xi, [\rho], pos\rangle$ that contains the linking information (R = semantic role, d = distributivity, s = event scope, ξ = exhaustiveness, ρ = repetitiveness or repetition frequency). For the most common link structure, a quintet with positive polarity and ξ = non-exhaustive (abbreviated 'nex'), the interpretation of the link structure is specified by (B28):

(B28) a. If d = individual or d = parts, then $I_Q(R, d, narrow, nex, pos) = I_Q(R, parts, narrow, nex, pos) =$
$[\ X \mid x \in X \rightarrow [\ E \mid e \in E \rightarrow R(e,x)\ ]]$

b. If d = individual or d = parts, then $I_Q(R, d, wide, nex, pos) = I_Q(R, parts, wide, nex, pos) =$
$[\ E \mid e \in E \rightarrow [\ X \mid x \in X \rightarrow R(e,x)\ ]]$

c. $I_Q(R, collective, narrow, \xi, pos) = [\ E, X \mid e \in E \rightarrow R(e,X)\ ]$

d. $I_Q(R, collective, wide, \xi, pos) = [\ E \mid e \in E \rightarrow [\ X \mid R(e,X)\ ]]$

e. $I_Q(R, unspecific, narrow, nex, pos) = [\ X \mid x \in X \rightarrow [\ E \mid e \in E \rightarrow [\ y \in X^* \mid x=y \vee x \in y, R(e,y)\ ]]]$

f. $I_Q(R, unspecific, wide, nex, pos) = [\ E \mid e \in E \rightarrow [\ X \mid x \in X \rightarrow [\ y \in X^* \mid x=y \vee x \in y, R(e,y)\ ]]]$

g. $I_Q(R, single, s, \xi, pos) = [\ x, E \mid e \in E \rightarrow R(e,x)\ ]$

14 The 'anaphoric scoped merge' and the auxiliary operation of 'anaphoric substitution' are potentially also useful for dealing with reflexives.

B3.1.2 Links with negative polarity

Participation link structures with negative polarity come in two varieties: for wide-scope negation, when the negation outcopes all quantifications over participants and events, and for narrow-scope negation, as in the readings b and c, respectively, of the sentence in (B29a).

(B29) a. The unions do not accept the proposal.
b. It is not the case that all the unions accept the proposal.
c. All the unions do not accept the proposal (none of them accepts it).

The meaning of a clause with a wide-scope negation is the negation of the same clause without the negation. This is expressed in (30), where the negation operator at DRS top-level is used that was introduced by Krahmer & Muskens 1995), symbolized as '~'. (Standard DRT only allows negation of sub-DRSs, which leads to problems in dealing with negated and disjunctive sentences; see e.g. Krahmer, 1995 and Qian, 2015). If the polarity of the link has narrow scope then (B31) applies, which makes use of a combinator that brings the event information of a participation link within the scope of the negation. This combinator, symbolized as $\oplus^n$, is defined in (B32).

(B30) $I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, s, \xi, \rho, \text{neg-wide}\rangle) = \sim I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, s, \xi, \rho, \text{pos}\rangle)$

(B31) $I_Q(\langle \varepsilon_E, \varepsilon_P, R, d, s, \xi, \rho, \text{neg-narrow}\rangle) = I_Q(\varepsilon_P) \cup (I_Q(R, d, s, \xi, \rho, \text{neg-narrow}) \oplus^n I_Q(\varepsilon_E))$

(B32) $[\, X \mid C_1,\; x \in X \rightarrow \neg K_1] \oplus^n K_2 =_D [\, X \mid C_1,\; x \in X \rightarrow \neg(K_1 \cup K_2)\,]$

B3.1.3 Exhaustive linking

Exhaustive linking occurs when the set of individuals involved in a quantified predication contains all the participants of which the predication is said to hold, as in *"(Only) Two people attended the wedding".* and in *"(Only) Two colleagues did not attend the wedding".* The exhaustiveness can be expressed by stipulating that the discourse referent (set) in the link interpretation (for which mostly 'X' is used) does contain all these individuals; see e.g. the bidirectional in (B33a,b). If the distributivity of the link is collective or single, then the notion of exhaustiveness by its very nature does not apply, and in some cases the event scope does not either. This is expressed in (B33c-e), where 's' stands for any event scope, 'ξ' for any exhaustiveness, and 'neg' for either 'neg-wide' or 'neg-narrow'.

The interpretation of quintuples $\langle R, d, s, \xi, p\rangle$ with ξ = 'exhaustive' is defined in (B33) (cf. (B28)):

(B33) a. $I_Q(R, \text{individual, narrow, exhaustive, pos}) = I_Q(R, \text{parts, narrow, exhaustive, pos}) =$
$[\, X \mid x \in X \leftrightarrow [\, E \mid e \in E \rightarrow R(e,x)\,]]$
b. $I_Q(R, \text{individual, wide, exhaustive, pos}) = I_Q(R, \text{parts, wide, exhaustive, pos}) =$
$[\, E \mid e \in E \rightarrow [\, X \mid x \in X \leftrightarrow R(e,x)\,]]$
c. $I_Q(R, \text{unspecific, narrow, exhaustive, pos}) =$
$[\, X \mid x \in X \leftrightarrow [\, E \mid e \in E \rightarrow [\, y \in X^* \mid x{=}y \vee x \in y, R(e,y)\,]]]$
d. $I_Q(R, \text{unspecific, wide, exhaustive, pos}) =$
$[\, E \mid e \in E \rightarrow [\, X \mid x \in X \leftrightarrow [\, E, y \in X^* \mid x{=}y \vee x \in y, e \in E \rightarrow R(e,y)\,]]]$

The corresponding clauses for negative-polarity links are as follows;

(B34) a. $I_Q(R, \text{individual, narrow, exhaustive, neg-narrow}) = I_Q(R, \text{parts, narrow, exhaustive,}$

neg-narrow) = $[\ X \mid x \in X \ \rightarrow \neg[\ E \mid e \in E \ \rightarrow\ R(e,x)\ ]]$

I_Q(R, individual, narrow, exhaustive, neg-wide) = I_Q(R, parts, narrow, exhaustive, neg-wide) = $\sim [\ X \mid x \in X \leftrightarrow [\ E \mid e \in E \rightarrow R(e,x)\ ]]$

b. I_Q(R, individual, wide, exhaustive, neg-narrow) = I_Q(R, parts, wide, neg-narrow) = $[\ E \mid e \in E \ \rightarrow\ \neg[\ X \mid x \in X \leftrightarrow R(e,x)\ ]]$

I_Q(R, individual, wide, exhaustive, neg-wide) = I_Q(R, parts, wide, neg-wide) = $\sim [\ E \mid e \in E \ \leftrightarrow \neg[\ X \mid x \in X \leftrightarrow R(e,x)\ ]]]$

c. I_Q(R, collective, narrow, ξ, neg) = $[\ E, X \mid \neg[e \in E \ \rightarrow\ R(e,X)\ ]]$

d. I_Q(R, collective, wide, ξ, neg) = $[\ E \mid \neg[e \in E \ \rightarrow\ [\ X \mid R(e,X)\ ]]]$

e. I_Q(R, unspecific, narrow, exhaustive, neg-narrow) = $[\ X \mid x \in X^* \ \leftrightarrow \neg[\ E \mid e \in E \rightarrow R(e,x)\ ]]$

I_Q(R, unspecific, narrow, exhaustive, neg-wide) = $\sim [\ X \mid x \in X^* \ \leftrightarrow [\ E \mid e \in E \rightarrow R(e,x)\ ]]$

f. I_Q(R, unspecific, wide, exhaustive, neg-narrow) = $[\ E \mid e \in E \ \rightarrow\ \neg[\ X \mid x \in X^* \leftrightarrow\ R(e,x)\ ]]$

I_Q(R, unspecific, wide, exhaustive, neg-wide) = $\sim [\ E \mid e \in E \ \rightarrow\ [\ X \mid x \in X^* \leftrightarrow\ R(e,x)\ ]]$

g. I_Q(R, single, s, ξ, neg) = $[\ E, x \mid \neg[e \in E \ \rightarrow\ R(e,x)\ ]]$

B3.1.4 Repetitive linking

Participation in a k-times recurring event can be annotated by means of a participation link structure with repetitiveness k, the semantics of which is given by (B35) for the case of individual, non-exhaustive participation with narrow event scope:

(B35) I_Q(R, individual, narrow, nex, k, pos)) = $[\ X \mid x \in X \ \rightarrow [\ E\ ]\ k(E),\ e \in E \rightarrow R(e,x)\ ]]$

The addition of a repetitiveness specification to participation link structures leads to variants of the clauses (B28) - (B34) of the definition of I_Q, like (B35) is a variant of (B28a). A repetitiveness specification is a pair $\langle r, n\rangle$, where 'n' is a positive integer and 'r' is one of the numerical relations 'equal', 'greater than', 'greater than or equal', 'less than', 'less than or equal'; annotations of the form $\langle$equal, n$\rangle$ will be abbreviated by 'n'.

Temporal and spatial quantification by means of NPs where the head has a temporal (or spatial) character, as in (B37), naturally fall within the scope of the QuantML scheme. The combination of such a temporal quantification with an adverbial quantifier, as in (B37b), allows a treatment of frequency, as illustrated in (B38).

(B37) Some parents call every day.

(B38) Some parents call twice every day.

Markables: m1 = Some parents, m2 = parents, m3 = call, m4 = every hour, m5 = hour

Annotation representation:

```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="some" definiteness="indet'"/>
<sourceDomain xml:id="x2" target="#m2" pred="parent"/>
<event xml:id="e1" target="#m3" pred="call"/>
<entity xml:id="x3" target="#m4" domain="#x4" involvement="all" definiteness="det"/>
<sourceDomain xml:id="x4" target="#m5" pred="day"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="individual"
        evScope="narrow" repetition="2"/>
<participation event="#e1" participant="#x3" semRole="inTime" distr="individual"
        evScope="narrow"/>
<scoping arg1="#x1" arg2="#x2" scopeRel="wider"/>
```

Semantics:

$[\ X \subseteq \text{parent} \mid x \in X \rightarrow [\ D \subseteq \text{day}_0 \mid d \in D \rightarrow [\ E \subseteq \text{call} \mid |E| = 2, e \in E \rightarrow [\ \text{agent}(e,x), \text{intime}(e,d)\ ]]$

B3.2 Scope links

Scope links determine how the interpretations of participation link structures are to be combined to form DRSs that correctly represent the scope relations among the quantifiers in a clause.

For two quantifying NPs, the scope relation between the corresponding participant entity structures $\boldsymbol{\varepsilon_{P1}}$ and $\boldsymbol{\varepsilon_{P1}}$ is either that one outscopes the other ('wider'), or that they mutually outscope one another ('dual'), or that they have equal scope. The corresponding participation structures are combined by means of their scoped merge ($\cup^*$), their dual merge ($\cup^D$), or their DRS-merge ($\cup$) respectively.

A treatment of non-quantifying NPs (proper name, definite description, personal pronoun), which does not have an outscoping relation to a quantifying NP, is included in the annotation scheme defined in this document for convenience. A non-quantifying NP and a quantifying NP (or two non-quantifying NPs) are treated as related through a scope link structure with scoping relation 'unscoped', which triggers their interpretations to be merged by the 'unscoped merge' operator ($\cup'$). This operator combines the participant-related information in its arguments like the DRS-merge; the event-related information is merged in the scope-determined position in the quantifying NP annotation interpretation. (The event-related information in the non-quantifying NP can move around freely, as it has the event scope "free".)

(B41) specifies the semantics of the scope relations; (B42) shows the semantics of scope link structures.

(B41) $I_Q(\text{wider}) = \lambda x.\ \lambda y.\ x \cup^* y$; $I_Q(\text{equal}) = \lambda x.\ \lambda y.\ x \cup' y$; $I_Q(\text{dual}) = \lambda x.\ \lambda y.\ x \cup^D y$

(B42) a. $I_Q(\langle L_{P1}, L_{P2}, \text{wider}\rangle) = I_Q(\text{wider})(I_Q(L_{P1}), I_Q(L_{P2})) = I_Q(L_{P1}) \cup^* I_Q(L_{P2})$

b. $I_Q(\langle L_{P1}, L_{P2}, \text{equal}\rangle) = I_Q(\text{equal})(I_Q(L_{P1}), I_Q(L_{P2})) = I_Q(L_{P1}) \cup I_Q(L_{P2})$

c. $I_Q(\langle L_{P1}, L_{P2}, \text{dual}\rangle) = I_Q(\text{dual})(I_Q(L_{P1}), I_Q(L_{P2})) = I_Q(L_{P1}) \cup^D I_Q(L_{P2})$

d. $I_Q(\langle L_{P1}, L_{P2}, \text{unscoped}\rangle) = I_Q(\text{unscoped})(I_Q(L_{P1}), I_Q(L_{P2})) = I_Q(L_{P1}) \cup' I_Q(L_{P2})$

B4 Clause-level annotation structures

The annotation of a simple sentence (or 'clause'), consisting of a verb and its arguments, being the natural unit for quantification annotation, has the structure shown above in (66), viz.:$A = \langle \varepsilon_{EV}, \{\varepsilon_{P1},\ldots, \varepsilon_{Pn}\}, \{L_{P1},\ldots, L_{Pn}\}, \{sc_1,\ldots, sc_k\}\rangle$. The interpretations of the link structures $L_{P1},\ldots, L_{Pn}$ combine the interpretation of each participant structure with the event structure.

If A is a fully-scoped annotation structure then $I_Q(A)$ is the combination of $I_Q(L_{P1}), \ldots, I_Q(L_{Pn}\}$, where the pairwise combination of link structure interpretations is defined in (B42). As A is fully scoped, then there is a sequence $L_1,..L_n$ of participation link structures such that $L_i \in \{L_{P1},\ldots, L_{Pn}\}$ and that each pair of neighbours L_i, L_{i+1} is linked through one of the three possible scope relations. Let s_i designate the scope relation between L_i and L_{i+1}. The interpretation of the annotation structure is then computed as follows (using short notation $s_i' = I_Q(s_1)$ and $L_i' = I_Q(L_{1i})$:

(B43) $I_Q(A) = s_1'(L_1', s_2'(L_2', s_3(L_3', \ldots, s_{n-1}'(L_{n-1}', L_n'))) \ldots)$

If the scope relations in an annotation structure do not specify (explicitly or by implication) 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 a specification of scope constraints, together forming an underspecified DRS ('UDRS', Reyle, 1993).

B5 Example annotations with semantic interpretation

B5. Collective quantification

(B51) "Three men moved both pianos"

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

QuantML-XML annotation: Upon the collective reading for "Three men", the individual reading for "five pianos", and "Three men" outscoping "five pianos", the sentence is annotated as shown in (A6).

Abstract syntax: $A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle$, with

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

$\boldsymbol{\varepsilon_{P1}} = \langle m1, \langle\langle m2, man\rangle, 3, indeterminate\rangle\rangle$**,** $\boldsymbol{\varepsilon_{P2}} = \langle m4, \langle\langle m5, pianos\rangle, 2, determinate\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, Agent, individual, narrow\rangle$, $L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, Theme, unspecific, narrow\rangle$

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

Semantics:

The interpretation of the annotation structure is obtained by the scoped merge of the two participant link structures:

$$I_Q(A) = I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P!}), L(\varepsilon_E,\varepsilon_{P2}), \{\langle \varepsilon_{P2}, \varepsilon_{P1}, wider\rangle\}\rangle) = I_Q(L_{P2}) \oplus^s I_Q(L_{P1}) =$$
$$[\ Y \mid |Y| = 2, y \in Y \rightarrow piano(y),$$
$$y \in Y \rightarrow [\ X\ E \mid x \in X \leftrightarrow man_0(x), |X| = 3,\ e \in E \rightarrow [move(e), agent(e, X), theme(e, y)]\ ]\ ]$$

On the reading where *"Three men*" is outscoped by *"five pianos",* the interpretation of the annotation structure is obtained by applying the scoped merge to the same two arguments in reverse order:

$$I_Q(A) = I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{\langle \varepsilon_{P2}, \varepsilon_{P1}, wider\rangle\}\rangle) = I_Q(L_{P2}) \cup^* I_Q(L_{P1}) =$$
$$[\ Y \subseteq piano \mid |Y| = 5,\ y \in Y \rightarrow [X \subseteq man, E \subseteq move \mid |X| = 3,$$
$$e \in E \rightarrow [\ agent(e, X), theme(e, y)\ ]]]$$

'Group quantification': Collective quantification with wide event scope allows interesting readings of sentences with a collective quantification, as illustrated by example (B52). Upon the reading where groups of boys played with groups of girls (see example (27) in Section 2 6), i.e. where in each one of a certain set of play-events a group of seven boys and a group of eleven girls participated: the annotation of this sentence and its interpretation are as follows.

(B52) Seven boys played against eleven girls.

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

QuantML/XML annotation:

```
<entity xml:id="x1" #target="#m1" domain="#x2" involvement="7" definiteness="indet"/>
<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="indet"/>
<sourceDomain xml:id="x4" target="#m5" pred="girl" indiv="count"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="collective" evScope="wide"/>
<participation event="#e1" participant="#x3" semRole="agent" distr="collective" evScope="wide"/>
```

<scoping arg1="#x1" arg2="#x3" scopeRel="equal"/>

Abstract syntax:

A = $\langle\{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P1}), L(\varepsilon_E,\varepsilon_{P2}), \{\langle\varepsilon_{P1},\varepsilon_{P2},\text{unscoped}\}\rangle\rangle$ with

$\varepsilon_{P1} = \langle m1, \langle\langle boy,count\rangle, 7, indet\rangle\rangle$, $\varepsilon_{P2} = \langle m3, \langle\langle girl,count\rangle, 11, indet\rangle\rangle$, $\varepsilon_E = \langle m2, play\rangle$

$L(\varepsilon_E, \varepsilon_{P1}) = \langle\varepsilon_E, \varepsilon_{P1}, agent, group, wide\rangle$, $L(\varepsilon_E, \varepsilon_{P2}) = \langle\varepsilon_E, \varepsilon_{P2}, agent, group, wide\rangle$

$sc_1 = \langle \mathbf{L}_{P1}, L_{P2}, equal\rangle$

Semantics:

The intended interpretation is obtained by applying the scoped merge operation to the two participation link structures with the respective participant entity structures, and in view of the scope relation being 'equal', combining the results by the ordinary DRS-merge:

$I_Q(A) = I_Q(\langle\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L(\varepsilon_E,\varepsilon_{P1}), L(\varepsilon_E,\varepsilon_{P2})\}, \{\varepsilon_{P1},\varepsilon_{P2},unscoped\}\rangle) = I_Q(L(\varepsilon_E,\varepsilon_{P1}) \cup I_Q(L(\varepsilon_E,\varepsilon_{P2}))$

$I_Q(L(\varepsilon_E,\varepsilon_{P1}) = I_Q(\langle\varepsilon_E, \varepsilon_{P1}, Agent, group, wide\rangle) = (I_Q(\varepsilon_E) \cup I_Q(Agent, group, wide)) \oplus^s I_Q(\varepsilon_{P1})$

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

Result:

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

B5.2 Cumulative quantification

(B3) Three breweries supplied fifteen inns

QuantML/XML annotation: see (A11).

Annotation structure: A = $\langle\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle$, with

$\varepsilon_{P1} = \langle m1, \langle\langle brewery,count\rangle, 3, indet\rangle\rangle$, $\varepsilon_{P2} = \langle m3, \langle\langle inn,count\rangle, 15, indet\rangle\rangle$

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

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

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

$sc_1 = \langle L_{P1}, L_{P2}, dual\rangle$

A 'dual scope' relation between two participant structures is interpreted as mutual outscoping. Its interpretation involves the use of a merge operation somewhat similar to the 'scoped merge' operation, called 'dual-scope merge' and symbolised by $\cup^D$. The operation is defined for two arguments that have the form shown in (B54), where C_i is a (possibly empty) set of conditions, and K_i a DRS. The dual-scope merge of two such arguments is defined by (B56), and its use in specifying the semantics of the above annotation structure in is illustrated by (B57).

(B54) $[\ X_i \mid C_i,\ x \in X_i \rightarrow K_i\ ]$

(B56) $[\ X \mid C_1, x \in X \rightarrow K_1\ ] \cup^D [\ Y \mid C_2, y \in Y \rightarrow K_2\ ] =$
$= [\ X, Y \mid C_1 \cup C_2, x \in X \rightarrow K_1 \cup (K_2 \cup [\ y \mid y \in Y\ ]), y \in Y \rightarrow K_2 \cup (K_1 \cup [\ x \mid x \in X\ ]]$

(B57) $I_Q(A) = I_Q(\langle\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle) = I_Q(L_{P1}) \cup^D I_Q(L_{P2}) =$

$= [X \subseteq brewery, Y \subseteq inn \mid |X|=3, |Y|=15,$
$x \in X \rightarrow [Z \subseteq Y \mid y \in Z \rightarrow [E \subseteq supply \mid e \in E \rightarrow agent(e,x), beneficiary(e,y)]],$
$y \in Y \rightarrow [U \subseteq X \mid x \in U \rightarrow [E \subseteq supply \mid e \in E \rightarrow agent(e,x), beneficiary(e,y)]]]$

B5.3 Mass noun quantification

The most plausible reading of the example sentence (B58) sentence is the one where each of “the boys” participated in some beer drinking, and where all the beer was consumed by them. This is the cumulative reading, for which the QuantML annotation is a follows:[15]

(B58) The boys drank all the beer.

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

QuantML/XML representation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”all” definiteness=”det”/>
<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=”det”/>
<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=”parts” evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”dual”/>
```

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

$\varepsilon_E = \langle \text{m3, drink}\rangle$

$\varepsilon_{P1} = \langle \text{m1}, \langle\langle \text{m2}, \langle \text{boy,count}\rangle\rangle, \text{all, determinate}\rangle\rangle$

$\varepsilon_{P2} = \langle \text{m4}, \langle\langle \text{m5}, \langle \text{beer,mass}\rangle\rangle, \text{total, determinate}\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, \text{Agent, individual, narrow}\rangle$, $L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, \text{Theme, parts, det}\rangle$

$sc_1 = \langle L_{P1}, L_{P2}, \text{dual}\rangle$

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

$I_Q(\varepsilon_{P2})=I_Q(\langle \text{beer,total,det}\rangle) = [\ Y \mid \Sigma(Y) = \Sigma(\text{beer}_0),\ y \in Y \rightarrow \text{beer}_0(y)\ ]$

The interpretation of the annotation structure as a whole is thus:

$$I_Q(<\varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}>) = I_Q(L(\varepsilon_E,\varepsilon_{P1})) \cup^D I_Q(L(\varepsilon_E,\varepsilon_{P2})) = [X, Y \mid\mid$$
$$x \in X \rightarrow [y, E \mid e \in E \rightarrow \text{drink}(e), y \in Y, \text{boy}(x), \text{beer}(y), \text{agent}(e,x), \text{agent},y)],$$
$$y \in Y \rightarrow [x, E \mid e \in E \rightarrow \text{drink}(e), x \in X, \text{boy}(x), \text{beer}(y), \text{agent}(e,x), \text{patient}(e,y)]]$$

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 distinguished 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.

(B59) This truck has delivered more than fifty thousand litres of water.

Markables: m1=This truck, m2=truck, m3=delivered, m4=more than fifty thousand, m5=more than fifty thousand litres, m6=more than fifty thousand liters of water, m7=water

QuantML/XML annotation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”single” definiteness=“det”/>
<sourceDomain xml:id=”x2” target=”#m2” pred=”truck” indiv=”count”/>
<event xml:id=”e1” target=”#m3” pred=”deliver”/>
<participation event=”#e1” participant=”#x1” semRole=”agent” distr=”single” evScope=”free”/>
<entity xml:id=”x3” #target=”#m6” domain=”#x4” involvement=”#a1” definiteness=“indet”/>
```

[15] For improved readability, henceforth sharp brackets enclosing single items will be suppressed, leading to e.g. $\varepsilon_E = \langle \text{m3, drink}\rangle$ instead of $\varepsilon_E = \langle \text{m3}, \langle \text{drink}\rangle\rangle$.

```
<sourceDomain xml:id=”x4” target=”#m7” pred=”water” indiv=”mass”/>
<measure xml:id=”a1” target=”#m5” num=”#n1” unit=”litre”/>
<numericalPred xml:id=”n1” target=”#m4” numRel=”greater” num=”50.000”/>
<participation event=”#e1” participant=”#x3” semRole=”theme” distr=”parts” evScope=”narrow”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”unscoped”/>
```

Abstract syntax: $A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L\varepsilon_{P1}, L_{P2}\}, \{sc_1\}\rangle$
$\varepsilon_E = \langle$m3, deliver$\rangle$
$\varepsilon_{P1} = \langle$m1, $\langle\langle$m2, $\langle$truck,count$\rangle\rangle$, single, determinate$\rangle\rangle$,
$\varepsilon_{P2} = \langle$m6, $\langle\langle$m7, $\langle$water,mass$\rangle\rangle$, total, determinate$\rangle\rangle$
$L_{P1} = \langle L_E, L_{P1}$, Agent, single, narrow$\rangle$, $L_{P2} = \langle L_E, L_{P2}$, Theme, parts, narrow$\rangle$

Annotation interpretation:

$I_Q(\varepsilon_{P1})$ = [$x \in truck_0$| $|truck_0|=1$], $I_Q(\varepsilon_{P2})$ = [$Y \subseteq water$ | $Vol(\Sigma(Y)) >$ (50.000,liter)]

$I_Q(L_{P1})$ = [$x \in truck_0$, $E \subseteq deliver$ | $|truck_0|=1$, $e \in E \;\rightarrow$ agent(e,x)]

$I_Q(L_{P2})$ = [$Y \subseteq water$ | $Vol(\Sigma(Y)) >$ (50.000,liter), $y \in Y \rightarrow$ [$E \subseteq deliver$ | $e \in E \rightarrow$ theme(e,y)]]

$I_Q(A) = I_Q(L_{P1}) \cup' \; I_Q(L_{P2})$ = [$x \in truck_0$, $Y \subseteq water$ | $|truck_0|=1$], $Vol(\Sigma(Y)) >$ (50.000,litre),
$y \in Y \rightarrow$ [$E \subseteq deliver$ | $e \in E \rightarrow$ [agent(e,x), theme(e,y)]]

B5.4 Quantification involving parts of individuals

(B60) Mario ate two and a half pizzas.

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

Annotation structure: $A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle$
$\varepsilon_E = \langle$m2, eat$\rangle$
$\varepsilon_{P1} = \langle$m1, $\langle\langle$Mario, count$\rangle$, single, definite$\rangle\rangle$
$\varepsilon_{P2} = \langle$m3, $\langle\langle$pizza, count/parts$\rangle$, 2.5, indefinite$\rangle\rangle$
$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}$, Agent, individual, narrow$\rangle$, $L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}$, Patient, unspecific, narrow$\rangle$
$sc_1 = \langle \varepsilon_{P2}, \varepsilon_{P1}$, wider$\rangle$

Annotation representation:

```
<entity xml:id=”x1” #target=”#m1” domain=”#x2” involvement=”single” definiteness=”det”/>
<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=”patient” distr=”infividual”/>
<scoping arg1=”#x1” arg2=”#x3” scopeRel=”wider”/>
```

Semantics:
$I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle)$ = [Y, x | $mario_0(x)$, $|mario_0|=1$, $|Y|^* = 2.5$, $x \in Y \rightarrow$
[E | $e \in E \rightarrow$ eat(e), pizza^(y), agent(e, z), patient(e,y)]]

B5.5 Proper names and definite descriptions

Proper names are treated as referring to a single entity, rather than as a quantifier. By annotating them with participant entity structures and participation link structures, they can take part in the compositional interpretation of clause annotations. Participant entity structures for proper names have the involvement ‘single’, and participation link structures have the distributivity ‘single’. The interpretation of such an entity structure, illustrated here by the DRS [$x|santa_0(x)$, $|santa_0|=1$] for the proper name “Santa”, reflects the presupposition that there is only one contextually distinguished referent in the reference domain, identified as “Santa”.

(B61) Santa gave the children a present

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

QuantML/XML annotation:

```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="single" definiteness="det"/>
<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="det"/>
<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="single evScope="free"/>
<participation event="#e1" participant="#x3" semRole="beneficiary" distr="individual"
        evScope="narrow"/>
<participation event="#e1" participant="#x5" semRole="theme" distr="individual" evScope="narrow"/>
<scoping arg1="#x1" arg2="#x3" scopeRel="unscoped"/>
<scoping arg1="#x3" arg2="#x5" scopeRel="wider"/>
```

Abstract syntax: $A = \langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}, \varepsilon_{P3}\}, \{L\varepsilon_{P1}, L_{P2}, L_{P3}\}, \{sc_1, sc_2\}\rangle$

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

$\varepsilon_{P1} = \langle m1, \langle\langle m1, \langle santa, count\rangle\rangle\ single, det\rangle\rangle$, $\varepsilon_{P2} = \langle m3, \langle\langle m4, \langle present, count\rangle\rangle, all, def\rangle\rangle$

$\varepsilon_{P3} = \langle m5, \langle\langle m6, \langle xandra, count\rangle\rangle, single, det\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, Agent, single, free\rangle$, $L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}, Theme, unspecific, narrow\rangle$

$L_{P3} = \langle \varepsilon_E, \varepsilon_{P3}, Goal, single, free\rangle$

$sc_1 = \langle L_{P1}, L_{P2}, unscoped\rangle$, $sc_2 = \langle L_{P1}, L_{P3}, unscoped\rangle$, $sc_1 = \langle L_{P3}, L_{P2}, unscoped\rangle$

Semantics:

$I_Q(\varepsilon_{P1}) = [\ x \mid santa_0(x), |santa_0|=1]$, $I_Q(\varepsilon_{P2}) = [\ Y \mid y \in Y \leftrightarrow child_0(y)\ ]$, $I_Q(\varepsilon_{P3}) = [\ Z \mid z \in Z \rightarrow present(z)]$

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

$I_Q(L_{P1}) = [\ x, E \subseteq give \mid santa_0(x), |santa_0|=1, e \in E \rightarrow agent(e,x)\ ]$

$I_Q(L_{P2}) = [\ Y = child_0 \mid y \in Y \rightarrow [\ E \subseteq give \mid e \in E \rightarrow beneficiary(e,y)\ ]\ ]$

$I_Q(L_{P3}) = [\ Z \subseteq present \mid z \in Z \rightarrow [E \subseteq give \mid e \in E \rightarrow theme(e,z)\ ]\ ]$

$I_Q(A) = I_Q(L_{P1}) \cup' (\ I_Q(L_{P2}) \cup^* I_Q(L_{P3})) = [\ x, Y = child_0 \mid santa_0(x), |santa_0|=1,$

$y \in Y \rightarrow [Z \subseteq present \mid z \in Z \rightarrow [\ E \subseteq give \mid e \in E \rightarrow [\ agent(e,x), beneficiary(e,y), theme(e,z)$

]]]]

(B62) The president ate two pizzas.

Markables: m1=The president, m2=ate, m3=two pizzas, m4=pizzas

QuantML/XML annotation:

```
<entity xml:id="x1" #target="#m1" domain="#x2" involvement="single" definiteness="det"/>
<sourceDomain xml:id="x2" target="#m1" pred="president" indiv="count"/>
<event xml:id="e1" target="#m2" pred="eat"/>
<entity xml:id="x3" #target="#m3" domain="#x4" involvement="2" definiteness="indet"/>
<sourceDomain xml:id="x4" target="#m5" pred="pizza" indiv="count"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="single" evScope="free"/>
<participation event="#e1" participant="#x3" semRole="theme" distr="infividual"
        evScope="narrow"/>
<scoping arg1="#x1" arg2="#x3" scopeRel="unscoped"/>
```

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

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

$\varepsilon_{P1} = \langle$m1, $\langle\langle$president, count$\rangle$, single, determinate$\rangle\rangle$, $\varepsilon_{P2} = \langle$m3, $\langle\langle$pizza, count$\rangle$, 2, indeterminate$\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}$, Agent, single, narrow$\rangle$, $L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}$, Theme, individual, narrow$\rangle$

$sc_1 = \langle L_{P1}, L_{P2}$, unscoped$\rangle$

Semantics:

$I_Q(A) = I_Q(L_{P1}) \cup I_Q(L_{P2}) = [\ x, Y \subseteq pizza \mid president_0(x), |president_0|=1,$
$y \in Y \rightarrow [E \subseteq eat \mid e \in E \rightarrow [agent(e,x), theme(e,y)\ ]]]$

B5.6 Quantification with structured domains

(B63) Thirty-two Chinese students enrolled.

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

QuantM/XMLL annotation representation: see (A4).

Annotation structure: A = $\langle \varepsilon_E, \{\varepsilon_{P1}\}, \{L(\varepsilon_E,\varepsilon_{P1})\}, \{\}\rangle$, with

$\varepsilon_{P1} = \langle$m1, $\langle\langle$m4,$\langle$student,count$\rangle\rangle$,$\langle$m2, $\langle$Chinese,individual$\rangle\rangle$, 32, indet$\rangle\rangle$

$\varepsilon_E = \langle$m5, $\langle$enroll$\rangle\rangle$

$L(\varepsilon_E, \varepsilon_{P1}) = \langle \varepsilon_E, \varepsilon_{P1}$, Agent, individual, narrow$\rangle$

Semantics:

$I_Q(A) = I_Q(L(\varepsilon_E,\varepsilon_{P1})) = [\ X, E \mid |X|=32, x \in X \rightarrow [student(x), Chinese(x), [\ e \mid e \in E, enroll(e), agent(e.x)]\}$

(B64) Alex donated two of his books.

Markables:
m1 = Alex, m2 = donate, m3 = two of his books, m4 = his, m5 = his books, m6 = books

QuantML annotation representation:

```
<entity xml:id="x1" target="#m1" domain="#x2" involvement="single" definiteness="det"/>
<sourceDomain xml:id="x2" target="#m1" pred="alex"/>
<event xml:id="e1" target="#m2" pred="donate"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="single" evScope="free"/>
<entity xml:id="x3" target="#m3" domain="#x4" involvement="2" definiteness="indet" />
<qDomain xml:id="x4" target="#m4" source="#x5" restrictions="#r1"/>
<sourceDomain xml:id="x5" target="#m5" individuation="count" pred="book"/>
<possRestr xml:id="r1" target="#m3" distr="individual" possessor="#x1"/>
<participation event="#e1" participant="#x3" semRole="theme" distr="individual/>
<scoping arg1="#x3" arg2="x1" scopeRel="unscoped"/>
```

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

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

$\varepsilon_{P1} = \langle$m1, $\langle\langle$m1, $\langle$Alex,count$\rangle\rangle$, single, det$\rangle\rangle$

$\varepsilon_{P2} = \langle$m3, $\langle\langle\langle$m5, $\langle$book,count$\rangle\rangle$, $\langle$m4, $\langle$Poss,ε_{P1},individual,linear$\rangle\rangle\rangle$, 2, indet$\rangle\rangle\rangle$

$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}$, Agent, individual, narrow, non-exhaustive, positive$\rangle$

$L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}$, Theme, individual, narrow, non-exhaustive, positive$\rangle$

$sc_1 = \langle L_{P1}, L_{P2}$, unscoped$\rangle$

Semantics:

$I_Q(\varepsilon_{P1}) = [\ x \mid alex_0(x), |alex_0|=1\ ]$

$I_Q(\text{Poss}, I_Q(\varepsilon_{P1})) = \text{INA}_0((I_Q(\varepsilon_{P1},), \lambda u.\lambda v.\text{Poss}(v,u)) = \lambda z.\ [x \mid \text{alex}_0(x), |\text{alex}_0|=1, \text{Poss}(x,z)\ ]$

$I_Q(\varepsilon_{P2}) = [\ Y \subseteq \text{book} \mid |Y|=2, y \in Y \rightarrow [I_Q(\text{Poss}, I_Q(\varepsilon_{P1}))(y)\ ]$

$\quad = [\ Y \subseteq \text{book} \mid |Y|=2, y \in Y \rightarrow [\lambda z.\ [x \mid \text{alex}_0(x), |\text{alex}_0|=1, \text{Poss}(x,z)](y)\ ]$

$\quad = [\ Y \subseteq \text{book} \mid |Y|=2, y \in Y \rightarrow [x \mid \text{alex}_0(x), |\text{alex}_0|=1, \text{Poss}(x,y)]\ ]$

$I_Q(\langle A) = I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle = I_Q(L_{P1}) \cup' I_Q(L_{P2})$

$\quad = I_Q(\langle \text{donate}, \langle\langle\langle m6, \langle \text{book,count}\rangle\rangle,$
$\quad\quad \langle\langle\langle m3, \langle\langle \text{Poss}, \langle\langle \text{Alex,count}\rangle, \text{single, det}\rangle, \text{individual,linear}\rangle\rangle\rangle,$
$\quad\quad \text{Theme, individual, narrow, non-exhaustive, positive}\rangle) \cup'$
$\quad I_Q(\langle \text{donate}, \langle\langle \text{Alex,count}\rangle, \text{single, det}\rangle, \text{Agent, single, narrow, non-exhaustive, positive}\rangle)$

$\quad = [\ x \in \text{alex}_0, \mid |\text{alex}_0|=1, x \in X \rightarrow [\ E \subseteq \text{donate}\ [\ e \in E \rightarrow \text{agent}(e,x)\ ] \cup'$

$\quad\quad [\ Y \subseteq \text{book} \mid |Y| = 2, y \in Y \rightarrow [\ ,x \in \text{alex}_0,, E \subseteq \text{donate} \mid e \in E, \text{theme}(e,y), \text{Poss}(x,y)\ ]]$

$\quad = [x \in \text{alex}_0, Y \subseteq \text{book}, E \subseteq \text{donate} \mid |Y| = 2, e \in E \rightarrow \text{donate}(e), y \in Y \rightarrow$
$\quad\quad [\ e \mid e \in E, \text{book}(y), \text{Poss}(x,y), \text{agent}(e,x), \text{theme}(e,y)\ ]]$

B5.7 Quantification and negation

(B65) The girls did not smile, interpreted as "None of the girls smiled" (narrow-scope negation).

Markables: m1=The girls, m2=girls, m3=smile

QuantML/XML annotation:
<entity xml:id="x1" target="#m1" domain="#x2" involvement="all" definiteness="def'"/>
<sourceDomain xml:id="x2" target="#m2" pred="girl"/>
<event xml:id="e1" target="#m3" pred="smile"/>
<participation event="#e1" participant="#x1" semRole="agent" distr="individual"
eventScope="narrow" polarity="neg-narrow"/>

Abstract syntax: $A = \langle \varepsilon_E, \{\varepsilon_{P1}\}, \{L_{P1}\}, \{\}\rangle$
$\varepsilon_{P1} = \langle m1, \langle\langle m2, \langle \text{girl,count}\rangle\rangle, \text{all, det}\rangle\rangle$, $\varepsilon_E = \langle m3, \text{smile}\rangle$,
$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}, \text{Agent, individual, narrow, neg-narrow}\rangle$

Semantics:
$I_Q(A) = I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}\}, \{L_{P1}\}, \{\}\rangle) = I_Q(L_{P1}) = I_Q(\langle \varepsilon_E, \varepsilon_{P1}, \text{Agent, individual, narrow, neg-narrow}\rangle) =$
$\quad = I_Q(\langle \text{smile}\rangle, \langle\langle \text{girl,count}\rangle, \text{all, det}\rangle, \text{Agent, individual, narrow, neg-narrow}\rangle) =$
$\quad = [\ X \mid x \in X \leftrightarrow \text{girl}_0(x)\ ] \cup (\ [\ X \mid x \in X \rightarrow \neg[\ E \mid e \in E \rightarrow \text{agent}(e,x)\ ]] \oplus^n [\ E \mid e \in E \rightarrow$
$\quad\quad \text{smile}(e)\ ]\ ) =$
$\quad = [\ X = \text{girl}_0 \mid x \in X \rightarrow \neg[\ E \subseteq \text{smile} \mid e \in E \rightarrow \text{agent}(e,x)\ ]]$

B5.8 Exhaustive quantification

(B66) (Only) TWO dogs barked.

Markables: m1=Two dogs, m2=dogs, m3=barked

QuantML/XML annotation:
<entity xml:id="x1" target="#m1" domain="#x2" involvement="two" definiteness="indet"/>
<sourceDomain xml:id="x2" target="#m1" pred="dog"/>
<event xml:id="e1" target="#m2" pred="bark"/>

<participation event="#e1" participant="#x1" semRole="agent" distr="individual" evScope="narrow" exhaustivity="exhaustive"/>

Abstract syntax: A = $\langle \varepsilon_E, \{\varepsilon_{P1}\}, \{L_{P1}\}, \{\}\rangle$, with:
$\varepsilon_E = \langle$m3, bark$\rangle$,
$\varepsilon_{P1} = \langle$m1, $\langle\langle$m2, $\langle$dog,count$\rangle\rangle$, two, det$\rangle\rangle$
$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}$, Agent, individual, narrow, exhaustive, positive$\rangle$

Semantics:
$I_Q(\langle \varepsilon_E, \{\varepsilon_{P1}\}, \{L_{P1}\}, \{\}\rangle = I_Q(L_{P1})$
$= I_Q(\langle \varepsilon_E, \varepsilon_{P1}, \text{Agent, individual, narrow, exhaustive, positive}\rangle)$

$= [\, X \subseteq dog_0 \mid |X|=2, x \in X \leftrightarrow [E \subseteq bark \mid e \in E \rightarrow agent(e,x)]] \,]$

B5.9 Repetitive quantification

(A3) All the students read some of the papers twice.

Markables: m1=All the students, m2=students, m3=read, m4=some of the papers, m5=papers

QuantML-XML annotation: See (A3).

Annotation structure: A = $\langle \varepsilon_E, \{\varepsilon_{P1}, \varepsilon_{P2}\}, \{L_{P1}, L_{P2}\}, \{sc_1\}\rangle$, with
$\varepsilon_E = \langle$m3, read$\rangle$
$\varepsilon_{P1} = \langle$m1, $\langle\langle$m2, student, all, indet$\rangle\rangle$
$\varepsilon_{P2} = \langle$m4, $\langle\langle$m5, paper$\rangle$, some, det$\rangle\rangle$
$L_{P1} = \langle \varepsilon_E, \varepsilon_{P1}$, Agent, individual, narrow$\rangle$
$L_{P2} = \langle \varepsilon_E, \varepsilon_{P2}$, Theme, individual, narrow$\rangle$
$sc_1 = \langle \varepsilon_{P1}, \varepsilon_{P2}$, wider$\rangle$

Semantics:
$I_Q(\langle \varepsilon_E, \{\varepsilon_{P1},\varepsilon_{P2},\}, \{L_{E,P1}, L_{E,P2}\}, \{\langle \varepsilon_{P1},\varepsilon_{P2},\text{wider}\rangle\}\rangle) = I_Q(L_{E,P1}) \oplus^s I_Q(L_{E,P2}) =$

$= [\, X \mid x \in X \leftrightarrow student_0(x), x \in X \rightarrow [\, Y \subseteq paper_0 \mid y \in Y \rightarrow$
$[\, E \mid |E| = 2, e \in E \rightarrow [read(e), agent(e,x), theme(e,y)]]$