Towards Interoperable Annotation of Quantification

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Abstract

This paper presents an approach to the annotation of quantification that is under development in the context of an effort of the International Organisation for Standardisation ISO to define interoperable formalisms for semantic annotation. The paper focuses on the theoretical background and requirements for an ISO standard annotation scheme in this area.

1 Introduction

Quantification occurs when a predicate is applied to one or more sets of individual objects, as in example sentence (1):

(1) Santa gave the children a present.

A singular noun phrase like *a present* may seem to refer to a single object, but this sentence most likely does not mean that a single present was given to all the children, but rather that each one of a certain set of children was given a different present, so in this predication two sets of individuals are involved: a set of children and a set of presents (plus the set consisting of Santa, and a set of give-events).[1] In technical terms, the quantification over the children has wider scope than the one over presents. Relative scope is one of the most studied aspects of quantification in natural language (see e.g. Montague, 1971; Cooper, 1983; Kamp & Reyle, 1993; Szabolcsi, 2010; Ruys & Winter, 2011).

Another aspect is the 'distributivity' of a quantification, i.e. the question how a predicate is 'distributed' over a set of arguments, as exemplified by sentence (2), which is most likely intended to express that *"the piano"* was lifted collectively by *"the two men"*, rather than by each of the men individually.

(2) The two men lifted the piano.

Quantification occurs in almost every sentence in natural language, because of the occurrence of plural noun phrases that refer to sets of individual objects, and of singular noun phrases like *"a present"* in (1) that occur within the scope of other noun phrases.

The International Organisation for Standardisation ISO has in recent years established a number of standards for linguistic annotation in general, and semantic annotation in particular, in order to support the development of interoperable annotated corpora that are useful both for linguistic research and for language technology applications. In order to be applicable across theories and approaches, annotation standards should on the one hand be theory-neutral, but on the other hand take theoretical insights into account. This paper outlines an ISO standard annotation scheme under development for quantification, which builds on logical and linguistic theories of quantification, notably on the theory of generalized quantifiers and on the event-based semantics that is widely adopted in semantic theories and that underlies several other ISO schemes for semantic annotation.

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

2 Theoretical Background

2.1 Generalized Quantifier Theory

Quantification has been studied extensively in logic (Frege, 1879; Tarski, 1936; Mostowski, 1957; Lindström, 1966); in linguistics (Higginbotham & May, 1981: Keenan & Stavi, 1986; Zwarts, 1984; Partee, 1988; Szabolcsi, 2010; Ruys & Winter, 2011), in formal semantics (Montague, 1974; Barwise & Cooper, 1981; van Benthem, 1984; Westerstahl, 1985; Kamp & Reyle, 1993), and in computational semantics (Alshawi, 1990; Bos, 1995; Pulman, 2000; Robaldo, 2014). In logic, the study of quantification and its role in formal reasoning has long (from Aristotle to Tarski) been restricted to the use of the universal (∀, *"for all"*) and existential (∃, *"for some"*) quantifiers. Relatively recently (Mostowski, 1957; Lindström, 1966), it was noted that the universal and the existential quantifier can both be viewed as expressing a property of the involvement in a predication of sets of individual objects: the universal quantifier expresses that all the elements of a given domain are involved; the existential quantifier that at least one of them is involved. This notion of a quantifier has been generalized to other properties such as those expressed in English by *"most, less than half of, three"*, or *"more than 200"*. The concepts in this broader class of quantifiers are called *generalized quantifiers*.

According to the theory of generalized quantifiers (GQT), words like *all* and *some* in English, as well as their equivalents in other languages, do not form the counterparts of the universal and existential quantifiers of formal logic, and neither do words like *three*, and *most*, which have been called 'cardinal quantifiers' and 'proportional quantifiers' (Partee, 1988), form the counterparts of certain generalized quantifiers. In formal logic, quantifications are expressions like $\forall x.p$ and $\exists x.p$, which say that p is true of all individual objects in the universe of discourse and of at least one such object, respectively. In natural languages, by contrast, it is not possible to say in a similar way that something is true for all objects or for some object. The English expressions that are closest to the universal and existential quantifiers of formal logic are *"everything, something"*, and *"everybody, 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 indicate a certain domain that the quantification refers to. GQT therefore views noun phrases as quantifiers in natural language, rather than determiners (Barwise and Cooper, 1981). Determiners, instead, denote mappings from sets of entities to logical quantifiers (properties of sets of individual objects).

2.2 Event-based semantics

Some aspects of sentence meaning can be accounted for only if verbs are viewed as introducing events (in a broad sense of 'event', that includes states, facts, processes, and their negations), rather than predicates. Adverbial modifications are prime examples of this, and have prompted Davidson (1989) to introduce events as individual objects into the semantic of natural language, notably as additional arguments of predicates that correspond to verbs, as illustrated in (3a). Parsons (1990) has proposed a variation of this approach which does not increase the number of arguments of a verb-related predicate, but instead uses one-place predicates applied to existentially quantified event variables, and thematic roles, a.k.a. semantic roles, to represent the roles of the participants in events, as illustrated in (3b). This approach, known as 'neo-Davidsonian', has been widely adopted in modern semantics, and has been the basis of the ISO standard 24617-4 for the annotation of semantic roles.

(3) a. $\exists x.\exists y.\exists e.[present(x) \wedge child(y) \wedge give(e, santa, x, y)]$

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

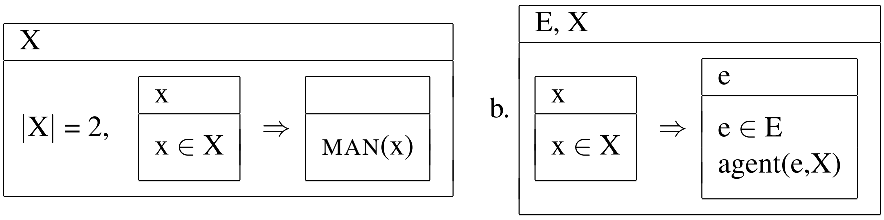
The latter representation makes the roles explicit of the participants in an event and has the advantage that it allows the representation of certain quantification aspects, such as the collective/individual distinction, as a property of the way in which a certain set of participants is involved in an event. The ISO 24617-4 annotation of (1) would look as in (4):

(4)
```
<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"/>
```

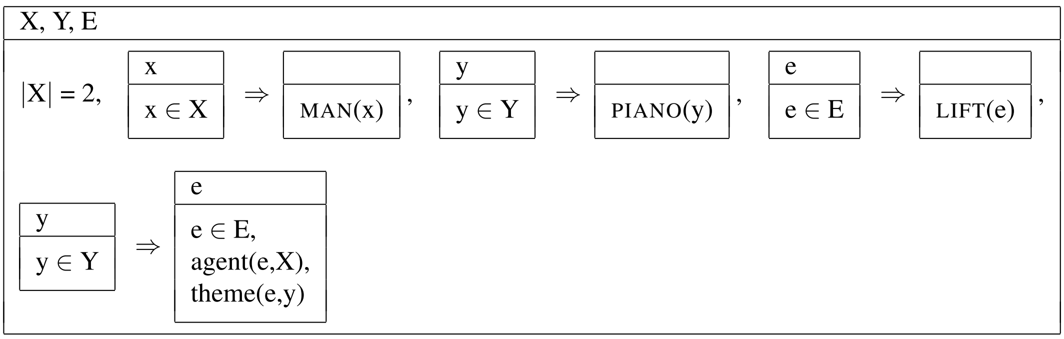
Quantifying expressions such as *"twice"* and *"more than five times"*, as in *"I called you twice"*, also necessitate the introduction of sets of events, since these expressions count the number of elements in a set of events of a certain type. Similarly for expressions of frequency, as in *"I will call you twice every day"*.

For an annotation schema for quantification, this paper proposes an approach that combines GQT with the neo-Davidsonian view on predicate-argument relations, including the use of semantic roles (as defined in ISO 24617-4) for characterizing event participation. This is brought out most clearly in the semantics of the annotations, which makes use of Discourse Representation Structures (DRSs) that involve sets of events with sets of participants. For example, the annotation of the NP *"Two men"* is interpreted as the DRS in (5a), which can be read as follows: *There is a set X of cardinality 2 that consists of men*. A semantic role link, like the one for the agent role with collective distributivity, is interpreted as the DRS in (5b), and the sentence *"Two men lifted a piano"* is interpreted as the DRS (6), obtained by combining the DRSs for the NPs, the verb, and the semantic role relations.

(5) a.



(6)



3 Related Work

Some work on the annotation of quantification has been going into ISO-TimeML (ISO 24617-1), which has certain limited provisions for dealing with time-related quantification. For example, a temporal quantifier like *"daily"* is represented as follows, where "P1D" stands for "period of one day":

(7)
```
<TIMEX3 xml:id="t5" target="#token0" type="SET" value="P1D" quant="EVERY"/>
```

The attribute @quant is used as one of the attributes of temporal entities, in order to indicate that the entity is involved in a quantification. ISOspace (ISO 24617-7) makes use of the same @quant attribute, but now applied to spatial entities, and in addition uses the attribute @scopes to specify a scoping relation. If the @scopes attribute for a <spatialEntity> tag with its ID being X is filled with the value Y, this relation means that the quantifier for X has scope over the quantifier for Y. The following example illustrates this:

(8) a. There's a computer$_{se1}$ on$_{ss1}$ every desk$_{se2}$.

b. <spatialEntity id="se1" target"#token2" form="nom" countable="true" quant="1",
scopes="∅"/>
<spatialEntity id="se2" target="#token5" form="nom" countable="true" quant="every"
scopes="#se1"/>
<spatialSignal id="ss1" target="#token3" type="dirTop" />
<qsLink id="qsl1" relType="EC" figure="#se1" ground="#se2" trigger="#ss1"/>
<oLink id="ol1" relType="above" figure="#se1" ground="#se2" trigger="#ss1"
frameType="intrinsic" referencePt="#se2" projective="false" />

('EC' designating the spatial relation 'externally connected'.) This is intended to correspond to the following formula in predicate logic, which says that on every desk there is a computer (rather than that a certain computer is setting on every desk):

(9) $\forall \text{se2}\ \exists \text{se1}\ [[\text{DESK(se2)} \wedge \text{COMPUTER(se1)}] \leftrightarrow [\text{EC(se2,se1)} \wedge \text{ABOVE(se2,se1)}]])$

The limitations of this approach for annotating temporal quantification have been discussed by Bunt & Pustejovsky (2010), and improvements have been suggested by Lee & Bunt (2012).

Indirectly related to the definition of an annotation scheme for quantification is the Groningen Meaning Bank project (Bos et al., 2017) at the University of Groningen, which is developing a resource consisting of sentences paired with DRSs that represent their meanings. This work cannot be compared directly with the usual kind of annotation work, which associates pieces of semantic information with individual words and small stretches of text like phrases and clauses, whereas in the Groningen Meaning Bank DRSs are associated with full sentences. It may however be interesting to compare these DRSs with those that come out of the compositional interpretation of annotations as pursued here.

4 Quantification Information to be Annotated

4.1 Quantification domains

NPs, expressing generalized quantifiers in natural language, consist of two parts: (1) a prenominal expression, including determiners such as *"all", "some", "the", "a", "most", "all five", and "less than 200"*, and (2) a noun or nominal complex. This second part, called the *restrictor*, indicates a certain domain that is considered in the quantification. We use the term *'source domain'* to refer to this set of entities (or, alternatively, to the characteristic property of these entities; cf. Gawron, 1996). The fundamental difference between quantification in logic and quantification in natural language, mentioned in Section 2.1, is reflected in the fact that natural language quantifiers have this restrictor component.

Quantification in natural language is very often restricted to a contextually determined part of the source domain, the *'reference domain'*, also called 'context set' (Westerstahl, 1985; Partee et al., 1990). For example, the quantifier *"everybody"* in (10a) does not apply to every person, but only to the reference domain consisting of the students in a particular class, and in (10b) the quantifier *"all the twenty-seven countries"* refers to a contextually determined set of 27 countries (rather than to the source domain of all countries). The occurrence of a definite NP in general indicates that the domain of a quantification is restricted to a certain reference domain, rather than to its source domain; therefore the definiteness of an NP is an item of quantification information to be annotated.

(10) a. Everybody must hand in the essay before next Thursday, the 20th.

b. The proposal was accepted by all the twenty-seven countries

The prenominal part of a full-fledged NP may be a sequence of different types of determiners. Grammars commonly distinguish different classes of determiners, with different possible sequencing and co-occurrence restrictions. For example, in English grammar it is customary to make a distinction between predeterminers, central determiners, and postdeterminers (e.g. Quirk et al., 1972; Leech and Svartvik, 1975; Bennett, 1974). This classification can be made in such a way that the determiners in each class have a different function:

- predeterminers express the (absolute or proportional) quantitative involvement of the reference domain, and may, additionally, provide information about the distribution of a quantification over the reference domain;
- central determiners determine the definiteness of the NP, and thus co-determine a reference domain;
- postdeterminers contain information 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, and *"nine"* a postdeterminer. The information carried by the various kinds of determiners is to be captured in the annotation of quantifications.

(11) All my nine grandchildren are boys.

4.2 Scope and Distributivity

Scope and distributivity, briefly mentioned in the introduction, are two important aspects of quantification in natural language to be taken into account in annotations. Studies of scope in quantifying expressions have focused almost exclusively on the relative scopes of sets of participants, as in the classical example *"Everybody in this room speaks two languages"*. In logic it is customary to assume that the relative scopes of sets of participants are linearly ordered (but see Hintikka, 1973 and Sher, 1990 on 'branching quantifiers'), but in natural language there are clear cases where none of the quantifications has wider scope than another. An example is provided by (12):

(12) Three breweries supplied five inns

The intended reading here is not that each one of three breweries supplied each one of five inns (wide scope of *"three breweries"*), nor that each one of five inns was supplied by each of three breweries (wide scope of *"five inns"*), but that in total three breweries supplied in total five inns. In this total-total, or *cumulative* reading (Scha, 1981) the two quantifications have equal scope; the two cardinal determiners both indicate the amount of involvement of the respective reference domains in the predication.

Not only the relative scoping of sets of quantified *participants* is a semantically important issue, but also the relative scoping of participants and *events*. This is illustrated by the two possible readings of the sentence in (13):

(13) Everyone will die.

Besides the reading according to which everyone is mortal, there is also a reading which predicts an apocalyptic future event in which everyone will die. (Note that the latter interpretation involves the consideration of events in which multiple participants occupy the same role. Several approaches, such as those of the VerbNet and PropBank frameworks allow only a single occupant for each semantic role; the ISO approach to semantic role annotation (ISO 24617-4), does allow multiple participants in the same semantic role.) There is no way to represent this second reading without explicitly introducing events; (14a) and (14b) show how the two readings can be represented in first-order logic by assigning alternative relative scopes to the quantifications over events and participants:

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

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

In the annotation in (15) the relative scope of events and participants is marked up by means of the attribute ‘eventScope’ that has been added to the XML element <srLink> from ISO 24617-4. There is a tendency in natural language that quantification over events has narrow scope, so this attribute has the default value “narrow”.

(15) <entity xml:id=“x1” target=“#m1” entityType=“passenger”/>
<event xml:id=“e1” target=“#m2” pred=“die” time-“fut”/>
<srLink event=“#e1” participant=“#x1” semRole=“theme” eventScope=“wide”/>

The annotation of scope will thus make use of two relations: one between the sets of participants involved and one between each set of participants and the events in which they participate.

Distributivity comes in an obvious form in the distinction between individual (or ‘distributive’) and collective participation, but other cases must be distinguished as well. In example sentence (16) the three boys involved did not necessarily do all the carrying either collectively or individually, but where they may have carried some heavy boxes collectively and some other, less heavy boxes individually:

(16) The boys carried all the boxes upstairs

The quantifications in this sentence have ‘unspecific’ distributivity (Bunt, 1985); the sentence just says that all the boxes were somehow carried upstairs by the boys, Following Kamp & Reyle (1993), we use the notation X^* to designate the set consisting of the members of X and the subsets of X, and the predicate P^* to designate the characteristic function of the set X^*, where P is the characteristic function of X. Using moreover the notation R_0 to indicate the characteristic function of a reference domain that forms a subset of a source domain with characteristic function R, the interpretation of (16) can be represented in second-order predicate logic as follows:

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

The distributivity of a quantification is not a property of the set of participants in a set of events, but a property of the way of participating. This is illustrated by example (18), assuming that *“the men”* individually had a beer, and collectively carried the piano upstairs.

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

Distributivity should thus be marked up on the participation relation in the drinking and carrying events, as in the annotation fragment shown in (19), where the XML element <srLink> from ISO 24617-4 has been enriched with the attribute ‘distr’:

(19) <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”/>

4.3 Quantification and Modification

The restrictor part in a full-fledged NP is in the simplest case just a noun, but in general may contain adjectives and other expressions that modify the noun, such as other nouns (in noun-noun combinations in English, like *“bread crumbs”*, or as composite nouns in other languages, like *“broodkruimels”* in Dutch), prepositional phrases, and relative clauses. Moreover, conjunctions of nouns (possibly with modifications) may further add complexity to restrictors.

Modifications bring certain issues of quantification, such as scope and distributivity, e.g. the restrictor *"heavy books"* in the sentence *"Peter carried some heavy books"* may be interpreted as referring to certain books that are heavy each (distributive reading) or to a heavy pile of books (collective reading).

Scope issues arise in particular when a noun is modified by a PP, as in (20), where a quantification inside the PP takes scope over the one of the head noun. This phenomenon is known as 'inverse linking' (May, 1977; May and Bale, 2007; Ruys and Winter, 2011; Barker, 2014). The phenomenon of inverse linking with PP modification is widespread; especially the case of an universally quantified main NP and existentially quantified PP is quite common.

(20) Mr Kay met with a council member from every town that expressed an interest in the proposal.

It has been claimed in the literature that in the case of inverse linking the quantifier of the embedded NP always takes maximal scope, but this has been challenged by Szabolcsi (2010), who provides counterexamples.

To capture the relevant information related to quantification within a complex restrictor, the annotation of complex restrictors needs to be articulated in marking up the head noun that is central to the restrictor, and the various possible modifiers, with indications of their distributivity and of the scope inversion that may occur with PPs as well as (though less commonly) with relative clauses (Barker, 2014; Szabolsi, 2010).

5 Towards an ISO Standard Annotation Scheme

An ISO standard annotation scheme for the annotation of quantification should fit within the series of semantic annotation standards known collectively as the Semantic Annotation Framework (SemAF), ISO 24617. It should as such be compatible with the existing parts of SemAF: Part 1, Time and events; Part 2, Dialogue acts; Part 4: Semantic roles; Part 7: Spatial information, and Part 8: Discourse relations. Moreover, it should be defined according to the ISO Principles for semantic annotation (ISO 24617-6; see also Bunt, 2015, and Pustejovsky et al., 2017), which means that it should have a 3-part definition consisting of (1) an abstract syntax; (2) a concrete syntax; (3) a semantics. This formal definition should be supported by a metamodel that captures the fundamental concepts used in annotations and the way they are related. Appendix A contains the specification of such a metamodel for quantification.

For reasons of space, we leave any consideration of the abstract syntax of quantification annotations out of this paper. It may be noted, though, that following the ISO principles, the semantics of the annotations is specified for the abstract syntax, and *a fortiori* applies to any rendering of the abstract annotation structures. In particular, the ISO principles require every representation format for semantic annotations to be defined by a so-called 'ideal' concrete syntax, i.e. a syntax that is (1) complete, in the sense of defining a representation for every annotation structure defined by the abstract syntax; (2) unambiguous, i.e. every representation defined by the concrete syntax is a rendering of one annotation structure defined by the abstract syntax (see Bunt, 2010). Organizing the definition of annotations according to this 3-part setup with a semantics defined for abstract annotation structures and using only ideal representation formats has the advantage that alternative representations of the abstract annotation structures inherit the semantics of the abstract syntax, and the representations in any ideal format can be converted to any other ideal format in a meaning-preserving way. In other words, all ideal representation formats are semantically equivalent. A benefit of this approach is that it supports the design of user-friendly representations. While XML representations are convenient for automatic processing, they are not suitable for human use, but they can be automatically converted to other formats that are more convenient for use by human annotators and dialogue researchers.

As a simple example, the natural language quantifier expressed by the NP *"two men"* corresponds to an abstract annotation structure that pairs the markable for an occurrence of the expression *"two men"* with a quadruple of concepts as shown in (21a); a concrete representation in XML may look as in (21b); and the semantic interpretation as shown in (21c), obtained by applying the interpretation rule (22). Rules of this kind, where 'P' stands for the characteristic predicate of a source domain, as defined by the lexical semantics of an NP head noun, and C is a predicate that expresses quantitative involvement, as defined by the semantics of a determiner, form the specification of the compositional semantics of annotation structures.

(21) a. $\langle$man, some, indef, $\lambda z.|z| = 2\rangle$

b. <entity xml:id="x1" target="#m1" entityType="man" involvement="2"/>

c. $$\begin{array}{|l|}\hline \mathrm{X} \\ \hline |\mathrm{X}| = 2, \quad \begin{array}{|l|}\hline \mathrm{x} \\ \hline \mathrm{x} \in \mathrm{X} \\ \hline\end{array} \quad \Rightarrow \quad \begin{array}{|l|}\hline \quad \\ \hline \textsc{man}(\mathrm{x}) \\ \hline\end{array} \\ \hline\end{array}$$

(22) $$\mathrm{V}(\langle \mathrm{P}, \text{some}, \text{indef}, C\rangle) = \begin{array}{|l|}\hline \mathrm{X} \\ \hline C(|\mathrm{X}|), \quad \begin{array}{|l|}\hline \mathrm{x} \\ \hline \mathrm{x} \in \mathrm{X} \\ \hline\end{array} \quad \Rightarrow \quad \begin{array}{|l|}\hline \quad \\ \hline \mathrm{P}(\mathrm{x}) \\ \hline\end{array} \\ \hline\end{array}$$

6 Concluding Remarks

In this paper we have indicated some of the most important requirements for the specification of an ISO standard annotation scheme for quantification, focusing on the theoretical foundations provided by (1) the theory of generalized quantifiers; (2) a neo-Davidsonian approach to events and their participants; (3) the separation of the abstract and concrete syntax of annotations, following the distinction between annotations and their representations as made in the ISO Linguistic Annotation Framework (ISO 24612; cf. Ide and Romary, 2004) and elaborated in the ISO Principles of semantic information, with (4) its way of associating a semantics (using higher-order Discourse Representation Structures) with abstract annotation structures, abstracting away from representation formats.

We have identified a number of properties of quantification in natural language that have to be taken into account in a semantically adequate annotation scheme, including those that occur in noun modification structures with quantifier restrictors, such as the distributivity of adjectival modification and inverse linking in modification by preposition phrases.

The specification of an annotation scheme following the theoretical directions indicated in this paper is in preparation as a new part of the ISO Semantic Annotation Framework (SemAF, ISO 24617).

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Appendix A. Specification of a metamodel for quantification annotation

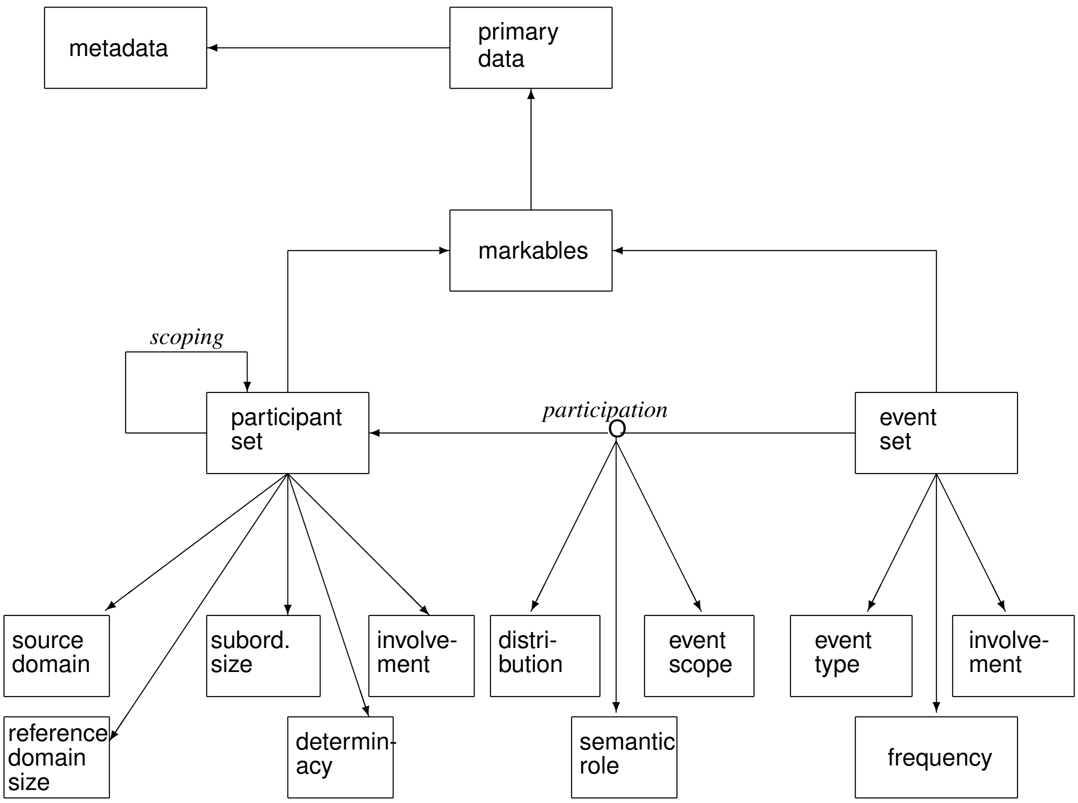

Figure 1: Metamodel for the annotation of quantification