Aspect, quantification and plurality

A dissertation proposal by
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Abstract

The goal of this dissertation is twofold. First, we aim to identify the source of distributivity in natural language. Our hypothesis is that throughout the grammar, distributivity can be tracked down to a single operator. Two converging lines of reasoning help us identify this operator. One line emerges as a result of generalizing and unifying previously disparate treatments of distributivity in the domain of nominal quantifiers. The other line comes from analyzing the meaning of durative adverbials, with special attention to their interaction with cumulative readings.

Second, we aim to provide a unified formal semantic framework for the treatment of interactions between verbs and their arguments, most importantly aspect, plurality, and quantification, and to shed light on the way in which thematic arguments are associated with the verb in the lexicon and in the compositional process. Although existing frameworks deal with parts of this picture, no such unified framework exists to date.

The theoretical results presented in this proposal include a novel argument in favor of a quantificational analysis of durative adverbials (Dowty, 1979; Moltmann, 1991); a novel account of cumulativity and distributivity that covers both the two-quantifier and three-quantifier case in the nominal domain, including readings prominently discussed by Schein (1993); a reason for severing not only the external, but also the internal argument from the semantics of the verb, in response to Kratzer (1996); and the first event-based semantics for Tree-adjoining grammar (TAG, Joshi et al., 1975).

Contents

1 Introduction

1.1 Scope of inquiry

The goal of this dissertation is twofold. First, we aim to identify the source of distributivity in natural language. Our hypothesis is that throughout the grammar, distributivity can be tracked down to a single operator. Two converging lines of reasoning help us identify this operator. One line emerges as a result of generalizing and unifying previously disparate treatments of distributivity in the domain of nominal quantifiers. The other line comes from analyzing the meaning of durative adverbials, with special attention to their interaction with cumulative readings.

Second, we aim to provide a unified formal semantic framework for the treatment of interactions between verbs and their arguments, most importantly aspect, plurality, and quantification, and to shed light on the way in which the-

matic arguments are associated with the verb in the lexicon and in the compositional process. Although existing frameworks deal with parts of this picture, no such unified framework exists to date.

Two of the arguably most successful existing frameworks dealing with some of these phenomena are Krifka (1986, 1992, 1998)'s theory of nominal reference and aspect and Landman (1996, 2000)'s theory of plurals and quantification. These theories share two fundamental assumptions: First, following Davidson (1967), they make explicit reference to events; second, following Link (1983), they assume that the domains of individuals, events, and time intervals are each ordered by a mereological, or part-of, relation. Atomic elements – those that have no parts – are used to represent singular individuals and events; composite elements or sums – those that have parts – correspond to plural individuals and events. Since the two frameworks share these assumptions, as well as a common Chomskyan view of the grammar, it appears feasible and promising to combine them into a unified theory. At the same time, the merging is not trivial. As we will see, changes need to be made to each framework before we can integrate them. In some cases, combining the theories will also suggest choices within the constituting frameworks. In these cases, the unification will shed new light on questions pertaining to each single framework that could previously not be answered conclusively within it.

Before turning to the benefits and challenges that arise from the combination of the existing frameworks, let us briefly describe the frameworks and the range of phenomena that they have been designed to cover.

Krifka (1998) provides a theory of telicity that predicts the distribution of durative adverbials like "for an hour" by correlating it with the aspectual properties of the verb phrase they modify (see Example 1):

(1) a. John ate apples for an hour.
     b. *John ate an apple for an hour.
     c. *John ate two apples for an hour.
     d. John pushed carts for an hour.
     e. John pushed a cart for an hour.
     f. John pushed two carts for an hour.

The VPs in these examples differ in their aspectual properties.[1] VPs like "eat an apple" or "eat two apples" are quantized (if they hold of an event, they don't hold of any parts of that event); VPs like "eat apples" or "push a cart" are homogeneous (if they hold of an event, they also hold of all the parts of that event). The quantized/homogeneous distinction is closely related to the telic/atelic distinction common in aspectology. For example, if John pushed a cart from 2pm to 3pm, or in event-semantic speak, if there is an event

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[1]Throughout this document, I use the term "aspect" to refer to what has been variously called inner aspect, lexical aspect, temporal constitution, or aktionsart, as opposed to the phenomenon referred to as outer aspect, grammatical aspect, or viewpoint aspect. I understand inner aspect as including phenomena such as telicity, and outer aspect as including the distinction between imperfective and perfective, and similar phenomena. Outer aspect will not be discussed in this proposal.

of John pushing a cart from 2pm to 3pm, then there is also a shorter event of John pushing a cart from 2pm to 2:30pm. By contrast, quantized event properties apply to events that either do not have parts, or only have parts to which the description does not apply. For example, if John ate two apples from 2pm to 3pm, then there may be shorter events that are parts of this event (for example, the eating of the first apple is one such event), but these events do not again fall under the description "eat two apples". These differences are ultimately rooted in the meaning of the verb, but they are influenced by the choice of argument. Therefore, as illustrated in (1), the entire VP, if not the entire sentence, determines whether durative adverbials like "for an hour" is licit. To predict the distribution of durative adverbials, Krifka claims that they presuppos that the VP they modify must be homogeneous with respect to time. That is, if the VP applies to an event, it must also apply to all of its subevents that are shorter.

Landman (2000) offers an analysis of the range of meanings the plural noun phrases exhibit. He argues for a basic distinction between collective and plural readings, attributes distributive and cumulative readings to plurality, and provides evidence for why plural readings should be generated by the grammar. For example, sentence (2) has, among others, *distributive* readings, such as the reading in which three boys each invited a potentially different set of four girls. It also has a reading that expresses that some boys invited some girls, the total number of boys inviting girls is three and the total number of girls invited by boys is four. This is the so-called *cumulative* reading.[2] In cumulative readings, the relation between quantifiers is symmetric. None of them outscopes the other. On the face of it, this is a challenge for a logical representation in which, as in predicate logic, quantifiers that bind variables of the same predicate are always ordered with respect to each other.

(2)   Three boys invited four girls.

Like Krifka, Landman assumes that individuals and events are each closed under sum. With the help of this assumption, and building on an idea he credits to Schein (1986), he is able to represent the cumulative reading of (2) in predicate logic. We will go into technical detail later, but essentially, Landman's representation of the cumulative reading asserts that there exist a sum of boys X, a sum of girls Y, and a sum of inviting events E, X is the sum of the agents of the atomic parts of E, and Y is the sum of the patients of the atomic parts of E.

Bringing aspect and plurality together opens up challenges and provides answers that cannot be found in either domain by itself. This dissertation proposes

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[2]A similar reading is the *collective* reading, in which there is a group of three boys that invited a group of four girls, where it is not necessarily the case that the individual boys issue an invitation. Whether cumulative and collective readings are distinct is not trivial to decide. See Roberts (1987) for a proposal to reduce cumulative readings to collective readings. In this dissertation proposal, I rely on the arguments from Landman (1996), who discusses some criteria for collectivity and argues that cumulative readings are not collective readings. for the independent existence of cumulative readings. This assumption is shared e.g. by Scha (1981); Schein (1993); Kratzer (1994).

to search for these challenges and answers. As an example, in section 3, we will encounter two proposals from the literature for the meaning "for an hour", one by Krifka (1998) and the other one by Moltmann (1991) building on Dowty (1979). At face value, both proposals are hard to distinguish empirically. However, once we look beyond simple sentences without quantifiers, we will notice that only one of these proposals, namely the Dowty/Moltmann proposal, is compatible with cumulative readings. More specifically, on the Dowty/Moltmann proposal, sentence (3) will be predicted to be consistent, while on Krifka's proposal, it will be self-contradictory, contrary to fact:

(3)　　Three professors interviewed four prospective graduate students for an hour, but it's not the case that every one of the professors interviewed every one of the prospective grad students at every moment throughout the hour.

As another example of fruitful interaction, bringing together quantification and aspect offers a novel line of inquiry into distributivity. Both Krifka's entry and the Dowty/Moltmann treatment of durative adverbials share the intuition that they have a presupposition that distributes a VP over subevents of an event. Distributivity is also widespread in the domain of nominal quantifiers. For example, on the surface-scope distributive reading of (2), there is a sum of three boys and each member of that sum invited a potentially different set of four girls. The question arises whether both cases of distributivity are really the same, or whether there are irreducible differences. To answer this question, it will first be necessary to see whether all distributivity in the domain of nominal quantifiers can be expressed by a single operator. After an excursion into two-quantifier (Landman, 2000) and three-quantifier (Schein, 1993) distributivity, we will answer this question with yes, and provide a novel operator to support this claim, at first only within the realm of nominal quantifiers. Then, we will see whether the same operator can be regarded as a building block of the meaning of "for an hour". Here, the answer will depend on whether we adhere to a Krifka-style or to a Dowty/Moltmann-style representation of durative adverbials. As it happens, it will turn out that only the Dowty/Moltmann proposal is compatible with distributivity in the nominal domain, thereby providing additional evidence for her representation.

In sum, bringing the theories of aspect and quantification together can bring clarity in either domain on questions which, on the face of it, have nothing to do with the other domain. It is the purpose of this work to create a unified framework in which these theories can both be expressed, and the benefits from their combination exploited. Technically, the framework will not claim any radical reorientation but will be kept compatible with the current style of formal semantic theory building. Therefore it is the hope that it will be compatible with other event-based theories, and can be integrated with them as needed.

The theoretical results presented in this proposal include a novel argument in favor of a quantificational analysis of durative adverbials (Dowty, 1979; Moltmann, 1991); a novel account of cumulativity and distributivity that covers both

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the two-quantifier and three-quantifier case in the nominal domain, including readings prominently discussed by Schein (1993); a reason for severing not only the external, but also the internal argument from the semantics of the verb, in response to Kratzer (1996); and the first event-based semantics for Tree-adjoining grammar (TAG, Joshi et al., 1975).

1.2   Plan of the proposal

In section 2, we briefly review some background assumptions concerning event semantics (Section 2.1) and the use of mereological structures for events and individuals (Section 2.2).

In Section 3, we review two competing proposals by Krifka (1998) and Dowty (1979); Moltmann (1991) concerning the meaning of aspect-sensitive durative adverbials such as *for an hour* (Section 3.1), and we show in detail how Landman's theory of cumulative readings can help us choose between them (Section 3.2). The basic fact on which we will rely is that only the entry based on Dowty and Moltmann, but not Krifka's entry, is compatible with cumulative readings as Landman's theory represents them.

In Section 4, we turn to distributivity in the domain of nominal quantifiers. We first review Landman (2000)'s theory of distributivity with two quantifiers (Section 4.1) and present the empirical landscape concerning distributivity with three quantifiers (Section 4.2). Based on proposals by Kratzer (1994, 1996) and by Schein (1986, 1993), as well as new data, we argue that both external and internal arguments must be severed from their verbs, and reformulate Landman's system accordingly (Section 4.3). We then show how to generalize the new system to sentences with three quantifiers (Section 4.4). As a result, we obtain a novel treatment of so-called Schein sentences, a class of three-quantifier readings with high theoretical significance for event semantics (Schein, 1986, 1993).

Section 5 is the centerpiece of this proposal. In this section, we show that there is a close connection between the generalized distributivity operator we have obtained in Section 4, and the distributive part of the meaning of durative adverbials we have obtained in Section 3. We start in Section 5.1 by decomposing durative prepositions into a thematic head and a distributivity operator, which turns out to be practically identical to the one we had obtained in the previous section. In Section 5.2, we provide independent evidence for this decomposition, and explore the option of unifying distributivity across both domains.

In Section 6, we briefly consider consequences of the present system for the syntax-semantics interface. We will see that the system is variable-free in the sense of Jacobson (1999), and arguably imposes a light load on the interface because syntax does not have to keep track of variables. As a proof of concept, a simple syntax-semantics interface to Tree-adjoining grammar is sketched. For ease of comparison, we add group-denoting noun phrases to the system, and thereby generate all eight readings of *Three boys invited four girls* listed in (Landman, 2000, ch. 6). The result is the first ever event-based semantics for TAG, which opens the door to a TAG semantic treatment of plurals, events,

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and quantification.

Section 7 lists areas of future research for the dissertation.

Exploring the derivations interactively

The Penn Lambda Calculator (Champollion et al., 2007) allows interactive, step-by-step viewing of semantic derivations in the typed λ calculus in a user-friendly, graphics-based environment. All derivations in this document have been checked for correctness with the help of this program, and the figures in the Appendix have been generated with it. A file that implements the semantic fragment described in this proposal is available at `http://www.ling.upenn.edu/~champoll/proposal/calculatorfile.txt`. Readers who would like to experiment with the fragment can easily edit this file with a regular text editor. To view the fragment, the "teacher edition" of the calculator is recommended. Please send requests to `champoll@ling.upenn.edu`.

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2 Background assumptions

In this section, we briefly review some background assumptions concerning event semantics (Section 2.1) and the use of mereological structures for events and individuals (Section 2.2).

2.1 Event semantics

Going back to at least Davidson (1967), much work in semantics accepts the idea that the appropriate logical representation of sentences involves explicit reference to events. A common motivation is the following. The fact that a sentence like (4a) logically entails (4b) cannot be captured by representing them as in (5) except with the help of meaning postulates. However, it follows from a representation as in (6).

(4) a. Brutus stabbed Caesar in the back with a knife.   Parsons (1990)
     b. Brutus stabbed Caesar.

(5) in(the-back, with(a-knife, stab(brutus, caesar)))
     $\nRightarrow$ stab(brutus, caesar)

(6) $\exists e.$ stab(e, brutus, caesar) $\wedge$ in(e, the-back) $\wedge$ with(e, a-knife)
     $\Rightarrow \exists e.$ stab(e, brutus, caesar)

The representation in (6) can be called classical – it follows Davidson's original proposal by treating arguments and adjuncts differently, since only adjuncts are related to the event by independent predicates. Not all event-based analyses share Davidson's particular view, however. Starting with Castañeda (1967),

many analyses have related arguments to the event by independent predicates as well, as in (7).

(7) $\exists e.\ \mathrm{stab}(e) \wedge \mathrm{agent}(e,\ \mathrm{brutus}) \wedge \mathrm{patient}(e,\ \mathrm{caesar}) \wedge \mathrm{in}(e,\ \mathrm{the\text{-}back}) \wedge$
    $\mathrm{with}(e,\ \mathrm{a\text{-}knife})$
    $\Rightarrow \exists e.\ \mathrm{stab}(e) \wedge \mathrm{agent}(e,\ \mathrm{brutus}) \wedge \mathrm{patient}(e,\ \mathrm{caesar})$

This view has come to be called *neo-Davidsonian*. Under this perspective, all differences between arguments and adjuncts are syntactic, since they behave the same semantically. Mixed representations are also found: Kratzer (1996) represents external arguments in the neo-Davidsonian way but internal arguments in the classical way. In Section 4.3, we will extend Kratzer's argument to internal arguments, and show that both the external and internal argument need to be separated from the event predicate in the semantics (see Schein (1993) for additional arguments to that effect).

2.2 Mereology

Perhaps more than anybody else, Link (1983) can be credited for bringing the notion of mereology into natural language semantics. I will not do justice to his system in his exposition, but confine myself to the barest of descriptions. I will introduce conventions later used by Landman and Krifka, as well as typing and typographic conventions for this document along the way. Also, while a large part of Link (1983) is devoted to the analysis of mass terms, I will ignore mass terms completely in this exposition, as they are not talked about in the rest of this document.

The core data motivating our subset of mereological theory, as far as individuals are concerned, are the inferences in (8):

(8) a. John and Mary walk. $\Rightarrow$ John walks.
    b. John and Mary built a raft. $\overset{?}{\Rightarrow}$ John built a raft.
    c. John and Mary gathered. $\not\Rightarrow$ John gathered.

Algebraic semantics imposes a assumes that the domain of individuals (type e) is ordered by a part-of relation, written $\leq$. We write $<$ to indicate the proper part relation, i.e. we have $a < b$ iff $a \leq b$ but not $a = b$. An individual is called the *sum* of all those individuals who are its parts. The domain of individuals is closed under sum (written $\oplus$), meaning that every sum of individuals is again an individual, and therefore denoted by type e. Parts are in fact defined in terms of the sum relation: $x \leq y$ iff $x \oplus y = y$. The denotations of conjoined noun phrases such as "John and Bill", for example, are assumed to be sums of individuals, $john \oplus bill$ in this case. By "atomic individual" we mean an individual that has no parts. When we say "sum individual" we mean an individual that has parts. Typically, certain axioms are imposed: The sum relation must be idempotent ($x \oplus x = x$, commutative ($x \oplus y = y \oplus x$), and associative: $x \oplus (y \oplus z) = (x \oplus y) \oplus z$.

Intuitively as well as mathematically, there are many similarities between the part-of and sum relations from mereology and the subset and union relations

from set theory. However, note that in our type theory, sums of individuals are again individuals (type e), while sets of individuals are of type $\langle e, t \rangle$, so the correspondence is not perfect. Also, in most applications of mereology, including those in natural language semantics, the *bottom element* (the entity which has no parts and which is a part of every other entity) is explicitly excluded, so that there is no mereological counterpart to the empty set.

The domain of events (type v) is also assumed to be structured by analogous relations for which we will also write $\leq$ and $\oplus$. The motiviation for this will be clear in the next section.

A special kind of atomic individuals called *groups* is used e.g. by Landman (2000) to model the behavior of predicates with a *collective* interpretation. Intuitively, these are predicates that can (or sometimes must) apply to sets of individuals without applying to their elements. Examples are *build a raft, lift a piano* as well as *gather, met in the hallway, be numerous*. The former are modeled as having both ordinary individuals and groups in their denotation; the latter only contain groups. Mathematically, a function $\uparrow(\cdot)$ is assumed to hold between any sum and the group that contains its members. For example, $\uparrow(john \oplus mary)$ is the group consisting of John and Mary.

Model-theoretic predicates are usually assumed to have only atomic individuals in their denotation, though some of these individuals can be groups. A star operator * maps a one-place predicate P to its closure under sum of its argument. That is, $^*P(x)$ iff x is the sum of a set of entities such that P is true of each member of that set. For example, if $walk(john) \wedge walk(bill)$ then $^*walk(john \oplus bill)$. * can be generalized to n-place predicates. It then performs pointwise closure under sum on each of the argument positions of the predicate. For example, if $loves(john, mary)$ and $loves(john, sue)$ and $loves(bill, sue)$ and $loves(bill, bill)$ then $^*loves(john \oplus bill, mary \oplus sue \oplus bill)$. From the definition of *, it follows that $^*walk(john \oplus mary) \Rightarrow walk(john)$. Observe that it does not necessarily follow that $gathered(\uparrow(john \oplus mary)) \Rightarrow gathered(john)$, since $\uparrow(john \oplus mary)$ is an atom, not a sum individual.

Events are assumed to be mapped to time intervals by the *temporal trace* function τ, also called the *runtime* function. Time intervals are also assumed to be mereologically ordered. The runtimes of events are not necessarily equal to the runtimes of their parts; for example, my running from 2pm to 2:30pm could (and generally will) be a part of my running from 2pm to 3pm. However, τ is assumed to be a homomorphism with respect to the sum operation: for any events e, e', we have $\tau(e) \oplus \tau(e') = \tau(e \oplus e')$. We could introduce a separate type for time intervals, as is sometimes done. But we will later generalize over individuals and time intervals, and for simplicity, we do not want to introduce type polymorphism into our grammar, so we will instead use type e both for times and ordinary individuals.

3 Cumulative readings help pin down durative adverbials

In this section, we review two competing proposals by Krifka (1998) and Dowty (1979); Moltmann (1991) concerning the meaning of aspect-sensitive durative adverbials such as *for an hour* (Section 3.1), and we show in detail how Landman's theory of cumulative readings can help us choose between them (Section 3.2). The basic fact on which we will rely is that only the entry based on Dowty and Moltmann, but not Krifka's entry, is compatible with cumulative readings as Landman's theory represents them.

3.1 Two proposals for durative adverbials

As mentioned in the introduction, durative adverbials like *for an hour* are sensitive to the aspectual properties of the predicate they modify. Example (1) (repeated below as (9)) shows the basic phenomenon:

(9)   a. John ate apples for an hour.   (= 1)
        b. *John ate an apple for an hour.
        c. *John ate two apples for an hour.
        d. John pushed carts for an hour.
        e. John pushed a cart for an hour.
        f. John pushed two carts for an hour.

Since at least Verkuyl (1972), compatibility with durative adverbials has been used as an indicator for atelicity (Vendler, 1957) – intuitively, the property of an event that does not have an inherent culmination point. As Verkuyl points out, and as shown by the contrast between (9a) and (9b-c), atelicity is not determined by the verb alone, but must be seen as a property at least of verb phrases. Therefore it cannot be determined by the lexicon alone. A theory of telicity must predict that *eat apples* is atelic, but *eat two apples* is telic.

The intuition pursued by both Krifka's and Dowty/Moltmann's analysis is that a durative adverbial requires that whenever the event predicate it modifies applies to an event, it also applies to a certain subset of parts (subevents) of this event. This will correctly explain the distribution of predicates like *eat an apple* or *eat two apples* with respect to durative adverbials because it can be independently shown that these predicates are *quantized* – whenever they apply to an event, they don't apply to any of its subevents. Both analyses differ, however, on exactly what is the relevant subset.

Let us take a look at the two analyses. Krifka's analysis has actually varied over the years, but his last version as stated in Krifka (1998) is as follows: [3]

(10) $[\![$for an hour$_{Krifka}]\!]_{\langle\langle e,vt\rangle,\langle e,vt\rangle\rangle}$
      Assertion: $\lambda R_{\langle e,vt\rangle}\lambda x_e\lambda e_v.R(x)(e) \wedge H'(e) = 1$
      Presupposition: $\exists e'[e' <_{H'} e] \wedge \forall e''[e'' \leq_{H'} e \rightarrow R(x)(e'')]$

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[3]The translation has been slightly adapted to respect the conventions in this document.

This entry takes a property of individuals and events R, an individual x, and an event e. Usually, R will be contributed by the verb phrase, x by the subject, and e by existential closure. The assertion of this entry states that the number of hours of the runtime of e is one. This is expressed by the function H' that maps entities to their runtimes in hours (with some special provisions for noncontinuous events that are irrelevant for the present point). The presupposition makes use of the relation $\leq_{H'}$, which is the part-of relation relativized to time. That is, $e' \leq_{H'} e$ iff e' is a part of e and there is another part of e whose runtime does not overlap with the runtime of e'. This will be the case if the runtime of e' is a proper part of the runtime of e. The presupposition itself states that the property R denoted by the verb phrase relates the subject to all the temporally shorter subparts of the event e, and that the event indeed has such temporally shorter subparts. For example, this requirement will exclude values of R like *eat an apple*, because an event to which *eat an apple* applies has no subevents, and in particular no temporally shorter subevents, which would again fall under the denotation of *eat an apple*.[4]

A closer look at Krifka's presupposition reveals that it entails the assertion (minus the duration statement $H'(e) = 1$), since the relation $\leq_{H'}$ is reflexive. This would predict that it statements like (11) should be self-contradictory:

(11) Perhaps John pushed a cart for an hour today, but perhaps he didn't touch any cart today.

Since the judgment on this sentence is not clear, we conclude that at least the distinction between assertion and presupposition is doubtful in Krifka's entry. However, we will not rest our case on this criticism, but simply note it for further work. The reasons that will ultimately lead us to reject Krifka's entry are different in nature, but the problem of distinguishing between assertion and presupposition will be present in the case of the Dowty/Moltmann entry as well. We will leave this problem for the dissertation. In the following, for convenience only, we will represent the semantic representations of *for an hour* sentences as if they were solely assertions.

Let us now turn to the analysis by Dowty (1979) and Moltmann (1991). Dowty gives a lexical entry that is not directly usable for our purpose because it does not refer to events. Moltmann recasts his idea in an event semantic framework. Although she does not give a concrete lexical entry, she describes her analysis as follows (Moltmann, 1991, p. 633):

> I take [durative adverbials] not to be event predicates at all, but rather quantifiers, namely universal quantifiers over the parts (subintervals or subregions) of some time interval (cf. Dowty, 1979) ...

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[4]The variable e occurs both in the assertion and in the presupposition. This is a problem in classical predicate logic – the famous *binding problem*. Without committing myself to details, I assume one of the usual technical solutions to this problem, e.g. dynamic semantics as presented in Beaver (2001). Krifka (1998) himself uses an operator δ to mark his presuppositions, but he does not define it.

(12) John played piano for two hours.   [=Moltmann's (10a)]

... (10a) [= our (12)] then means the following. For every subinterval t of some interval of two hours there is an event of playing piano by John which takes place at t. ... I will designate this part relation by 'P'. P has to be understood not as a part relation in a strict mereological sense, but rather as a contextually determined relation that may be coarser than the mereological part relation, as the relation 'is relevant part of' (cf. Moltmann, 1990a,b,c). One and the same entity may have different part structures depending on the respective context. For instance, a time interval may be conceived of as consisting of smallest subintervals of different length in different contexts – depending, for instance, on the type of events that are under consideration.

The restriction to relevant subintervals is designed to account for the *minimal parts problem*: If John runs for an hour, then it is not strictly speaking true that he runs at every subinterval, since running can only be defined over intervals that last at least a few seconds. Other predicates like *waltz* show this problem even more clearly: It takes at least the time of three steps to determine if somebody is waltzing (Dowty, 1979).

Later on (p. 634), Moltmann gives the following semantic translation for sentence (12):[5]

(13) $\exists t$ two-hours$(t) \; \wedge \; \forall t'[t'\mathrm{P}t \rightarrow$
       $\exists e \, [at(e, t') \; \wedge \; \text{play-piano}(e, john) \; \wedge \; \text{past}(t)]]$

This representation states that there is an interval t of two hours such that for every relevant part t' of t there is an past event at t' of playing the piano by John. Moltmann defines the relation 'at' as holding between an event e and an interval or region t just in case e coincides temporally or spatially with t. Since we are only interested in durative adverbials here, and in order to make comparison with Krifka's theory easier, we will use the equivalent $\tau(e)$ instead of at.

In a nutshell, and introducing some useful terminology, the difference between Krifka's and Moltmann's entry is the following. According to Krifka, a durative adverbial selects for a homogeneous predicate, one that applies to events as well as their shorter subevents. According to Dowty and Moltmann, a durative adverbial selects for a predicate that has the subinterval property: the predicate (or the sentence that contains it) must be true at an interval as well as being true all relevant subintervals. Apart from the role played by relevance, the difference is that the part-of relation between events is more fine-grained than between intervals. For example, suppose there is a sum event of John, Mary and Sue walking from 2pm to 3pm. Then we can find subevents of that event along two dimensions: They can be subevents because they are shorter, and they can

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[5]The translation has been slightly adapted to the conventions in this document.

be subevents because they involve less people, or both. By contrast, the we can only find subintervals of the 2-3pm interval along one dimension, namely time.

From the semantic representation in (13) and from her description, it is easy to derive a representation for *for an hour* that parallels Krifka's translation in (10) and captures Dowty's and Moltmann's idea. (13) contains a tense predicate, *past(t)*, but since tense is not a concern here I will disregard it.

(14) $[\![$for an hour$_{Dowty/Moltmann}]\!]_{\langle\langle e,vt\rangle,et\rangle}$
$= \lambda R_{\langle e,vt\rangle}\lambda x_e.\ \exists t\ [H(t) = 1]$
$\wedge\ \forall t'\ [t'\mathrm{P}t \rightarrow \exists e\ [R(x)(e) \wedge \tau(e) = t']]$

This entry takes an property R of individuals and events (the verb phrase) and an individual x (the subject). It states that there is an interval t whose duration is one hour (which I represented as $H(t) = 1$), and that for every relevant subinterval t' of t there is an event e' at t' such that R holds of the subject and that event. This would rule out quantized predicates like *eat an apple*. Since it is not possible to eat the same apple twice, this predicate cannot hold of every relevant subinterval of an hour, except in the sense where a different apple is eaten at every relevant subinterval. At the same time, a predicate like *push a cart* is not ruled out. If a cart is pushed for an hour, then this cart is also pushed at every relevant subinterval of this hour.

Krifka's and Dowty/Moltmann's entries are similar in that they both distribute R over events. But while Krifka's entry distributes R over every temporally shorter subevent of the event whose runtime is denoted by the durative adverbial, Dowty/Moltmann's entry distributes it instead over every event that takes place at a subinterval of the time denoted by the durative adverbial.

Since both entries make the right predictions concerning the basic phenomenon as illustrated in (9), it is difficult to choose among them. A full review of the arguments that Krifka and Dowty/Moltmann put forth for their respective proposals will be found in the dissertation. For now, we will show that cumulative readings of sentences with two quantifiers provide a novel argument for Dowty/Moltmann's entry.

3.2   Interaction with cumulative readings

The cumulative reading of a sentence like (15) has been discussed prominently by Scha (1981) and Landman (2000).

(15)   Three professors talked to four prospective graduate students.

On this reading, the sentence expresses that the total number of professors that talked to a prospective student is three and the total number of prospectives that were talked to by a professor is four. The reading is a *scopeless* reading in the sense that neither quantifier seems to take scope over the other; the relation between them is entirely symmetric.

There are different ways to represent cumulative readings, and not all of them make reference to events. For example, here is a representation of the cumulative reading of (15) without events:

(16) $\exists X \subseteq \{x \mid \text{professor}(x)\}. |X| = 3$
$\wedge \exists Y \subseteq \{y \mid \text{prospective}(y)\}. |Y| = 4$
$\wedge \forall x \in X \, \exists y \in Y \, [\text{talked-to}(x, y)]$
$\wedge \forall y \in Y \, \exists x \in X \, [\text{talked-to}(x, y)]\,]$

This formula states that there exist a set X of three professors and a set Y of four prospectives, each of the professors talked to one of the prospectives, and each of the prospectives was talked to by one of the professors.

Non-event-based accounts such as Scha (1981); Beck and Sauerland (2000) produce representations similar to (16), and the dissertation will contain a comparison of these accounts with the present one. However, in order to put either Krifka's or Dowty/Moltmann's event-based entry for durative adverbials to work, we do need to represent the reading in a way that makes reference to events, and we need to provide a compositional process that provides the right kind of meaning for the VP in order for the durative adverbials to modify it. This is where Landman's theory enters the picture, for as we will see, it provides exactly the desired semantic representation and compositional process.

Landman represents the cumulative reading of sentence (15) as follows:

(17) $\exists X \; {}^*\text{professor}(X) \; \wedge \; |X| = 3 \; \wedge$
$\exists Y \; {}^*\text{prospective}(Y) \; \wedge \; |Y| = 4 \; \wedge$
$\exists E \; {}^*\text{talk-to}(E) \; \wedge \; {}^*\text{ag}(E) = X \; \wedge \; {}^*\text{pat}(E) = Y$

This formula expresses that there is a sum E of one or more atomic talking events whose plural agent is a sum of three professors and whose plural patient is a sum of four prospectives. The plural agent of a (plural) event, written ${}^*\text{ag}$, is defined as the sum of all the agents of the atomic parts of that event, and similarly for the plural patient.

This representation may seem at first confusingly different from (16). How can it possibly capture the same meaning? The key to understanding Landman's representation is the following intuition. Descriptively, the cumulative reading of (15) says that there is a set of three boys that are involved in inviting girls, and there is a set of four girls that are involved in getting invited by boys. A bit more abstractly, we can say that the boys are the agents of the invitings, and the girls are the patients of the invitings. (Since we use a mereological setup, we use sums and not sets, but for the present purpose, when you read the word "sum" it doesn't matter if you think "set" or "sum".) The representation in (16) already provides us with a way of talking about the boys – X – and the girls – Y – and in addition, event semantics gives us a way of talking about the invitings – E. So, in an event semantic representation, we want X to be the agents of E, and we want Y to be the patients of E. Now what does it mean for X to be "the agents" of E? Here is a first attempt: it means that every member of X is an agent of E. But then E might still have some agents that are not in X. Here is a more successful attempt: X is "the agents" of E if every member of X is an agent in E, and every nonmember of X is not an agent in E. Now, this is equivalent to saying that X is the sum of the agents of the atomic events of E. And this is nothing else but the definition of plural agent.

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Landman credits this observation to Schein (1986).

Now that we have (hopefully) developed an intuition plural roles, let us train it by thinking about the interpretation of the formula in (17). The formula allows for the possibility that there is only one talking event (in which the three professors talk to the four prospectives simultaneously), or it may be that the sum consists of several talking events. There could be subevents in which, for example, professor number one talks to prospective student number one by himself for five minutes, but the formula will still be true in such a model, as long as by collecting together the participants of all the talking events you end up with three professors and four prospectives. This corresponds to our intuitions about cumulative readings.

Now, consider again the durative adverbial "for an hour". Take a sentence with a cumulative reading such as (15), and add "for an hour" to modify it, as in (18):

(18) Three professors talked to four prospective graduate students for an hour.

Based on what we have seen so far, we would expect that the adverbial should just take the cumulative reading and return it with the additional requirement that the value of its event variable is atelic and one hour long. Let us combine Krifka's and Dowty/Moltmann's entries with Landman's reading and see if this is indeed the case.

Since Landman's framework provides a quantifying-in operation, we can let "four prospectives" take scope over or under the adverbial. If it takes high scope, the four prospectives involved will be the same in each subevent, otherwise they may be different. Intuitively, the first option comes closest to the cumulative reading, so we will adopt it for presentation purposes, but the argument of this section would also go through if we chose the second option.

Krifka's entry produces the following representation (see Fig. 1):

(19) $\exists X$ *professor(X) $\wedge$ $|X| = 3$ $\wedge$
$\exists Y$ *prospective(Y) $\wedge$ $|Y| = 4$ $\wedge$
$\exists E$ *talk-to(E) $\wedge$ *ag$(E) = X$ $\wedge$ *pat$(E) = Y$ $\wedge$ $H'(E) = 1$ $\wedge$
$\exists e'[e' <_{H'} E]$ $\wedge$
$\forall e''[e'' \leq_{H'} E \to$ *talk-to(e'') $\wedge$ *ag$(e'') = X$
$\wedge \exists Y$ *prospective(Y) $\wedge$ $|Y| = 4$ $\wedge$ *pat$(e'') = Y]$

(19) states the existence of a sum X of three professors, of a sum Y of four prospectives, and of a sum of talking events E whose agents sum to X and whose patients sum to Y. So far, this is just the cumulative reading. It also states that the length of the runtime of this sum E is one hour. The notion of the runtime of a sum of events is perhaps hard to grasp, but remember that Krifka assumes that τ is a homomorphism with respect to the sum operation on events and time intervals. That is, for any two events e and e', we have $\tau(e \oplus e') = \tau(e) \oplus \tau(e')$, or in other words, the runtime of the sum of two events is the sum of their runtimes. So if we say that the runtime of E is one hour long, we mean that

by superimposing the runtimes of the parts of E we will get an interval whose duration is one hour.

(19) then goes on to state that the three professors are also the sum of the agents of each subevent of E with a runtime of less than an hour, and the sum of patients of each such subevent is a sum of four prospectives. It also ensures that there are such subevents. In particular, this means that the *atomic* subevents of E will always have everybody involved as their agents and patients.

This will only be true in a scenario where each of the three professors talks to the four prospectives at every moment of the entire hour. To show that this is so, we need to digress and establish an intermediary fact, namely that whenever an event e of talking to a sum of people temporally cooccurs with an event e' of talking to a part of these people, and the two events have the same agent, then e' must be a part of e. Alternatively, we could establish that there cannot be two distinct talking events at the same time and place with the same participants. For either of these facts, we need to appeal to intuitions, because they are not actually requirements of the usual mereological axioms. These axioms only give us the weaker statement that if there is an event e of you talking to John, Mary, and Sue, then there is also an event e' of you talking to John. As far as the axioms go, this event may temporally coincide with another event e'' of you talking to John that is not part of e. This will be laid out in more detail in the dissertation. So let us digress for a moment and think about the meaning of *talk*.[6]

3.2.1 Digression on the part-of relation of events

Suppose that I ask you what you did yesterday evening, and you tell me that you invited your friends John, Mary and Sue to your home and then the only thing you did then for an hour is talk to them. I say: "This cannot be true. You must have done something else during that hour, like offer them drinks or look out of the window". You might answer: "Yes, strictly speaking, I did other things besides talking to my friends. I gave them some drinks, and at some point I excused myself for a few moments to make a phone call." In a conversation like that, you might think that I am pedantic and annoying, but you might perhaps concede that I have a point, if not a very interesting one. Now suppose instead that I had answered: "This cannot be true. You must have done something else during that hour, like talk to John or talk to Mary." This case seems very different from the one above. You would most likely think of me as a lunatic, because your talking to John seems necessarily to be a part of your talking to John, Mary and Sue, and therefore I am wrong in using it as a counterexample to your claim. It is well known that in statements with *only*, when the focused element is a sum, then the parts of this sum are exempt from the uniqueness requirement that *only* imposes. For example, the statement "John and Bill came to the party" is not falsified by the fact that John came to the party,

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[6]The following reasoning is modeled after Kratzer (1989), but without her theoretical commitments. The correspondence between the part-of relation between events and her lumping relation between situations will be explored in the dissertation.

and in mereological terms, *john* is a part of *john* $\oplus$ *bill*. It seems, then, that whenever an event e of talking to a sum of people temporally cooccurs with an event e' of talking to a part of these people, and the two events have the same agent, then e' must be a part of e.

3.3   Back to the main plot

Now let us come back to the claim that (19) will only be true if each of the professors talks to the four prospectives at every moment of the entire hour. Here is a sketch of an argument why.[7] If, during that time, there was an event e where one of the professors talks to only one of the prospectives, then by the same reasoning we have just described, this event would be a part of the larger event, and so the restrictor of the universal quantifier in (19) would apply to it. But the nucleus of that quantifier would not apply to it because the sum of its patients is one prospective, not four. This causes (19) to be false.

The only kind of scenario that makes (19) true is a scenario in which at every moment throughout the hour, each of the professors talks to all the prospective students. This is not the cumulative reading anymore, but the so-called "branching" or "doubly distributive" reading, a subset of cumulative readings whose mere existence in English has been subject to controversy for a long time (Barwise, 1979; Gil, 1982; Sher, 1990, 1997).

Now, regardless of whether branching readings are otherwise attested, it might of course be the case that *for an hour* produces them. It is easy to test this by constructing a scenario in which (19) is violated. For example, if professor number one had a private conversation with prospective student number one for five minutes while the others are chatting away, that subevent would already falsify (19). More generally, according to Krifka's entry, any scopeless reading of the following sentence should be self-contradictory:

(20)   Three professors talked to four prospective students for an hour, but it's not the case that each of the professors talked to all the prospective students at every moment throughout the hour.

The point of sentence (20) is that its second conjunct explicitly rules out a branching reading, so that only the cumulative reading remains an option. But according to Krifka's entry, this reading is not an option.

Native speakers do not judge this sentence self-contradictory, suggesting that the cumulative reading is available. Accordingly, Krifka's presupposition for *for an hour* is too strong.

Let us now inspect the translation for sentence (15) that we get by applying Dowty/Moltmann's entry and see if it fares better. The derivation in Fig. 2 produces the following result:[8]

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[7]A proof will be added in the dissertation.

[8]As shown in Fig. 2, to generate this reading, we have raised *four prospectives* out of the VP to give it wide scope over the *for* adverbial. Otherwise, there would have been a potentially different sum of four prospectives for each relevant subevent. Alternatively (see

(21) $\exists X \ ^*\text{professor}(X) \ \wedge \ |X| = 3 \ \wedge$
$\exists Y \ ^*\text{prospective}(Y) \ \wedge \ |Y| = 4 \ \wedge$
$\exists t \ [H(t) = 1 \ \wedge$
$\forall t' \ [t'\mathrm{P}t \rightarrow \exists E \ [\tau(E) = t' \ \wedge \ ^*\text{talk-to}(E) \ \wedge \ ^*\text{ag}(E) = X \ \wedge \ ^*\text{pat}(E) = Y]]$

This states that there are a sum X of three professors, a sum Y of four prospectives and a time interval t whose length in hours is one; moreover, every interval t' that is a relevant part of t is the runtime of an potentially plural talking event whose agents sum to X and whose patients sum to Y. The relevant-part relation P is supposed to be contextually determined, so we have some leeway in interpreting it. But whichever way we choose P, this statement does not stand in contradiction to the second conjunct of (20). To see this, consider again a scenario in which there is a time t' at which professor number one talks to prospective student number one by himself for five minutes while everybody else is chatting away. Now either t' is a relevant subinterval of t (written $t'\mathrm{P}t$), or it is not, but in the latter case it will not affect the truth conditions of (21). Otherwise, i.e. if $t'\mathrm{P}t$, t' will not cause falsity as long as it is true at t' that the total number of professors that talk to a prospective is three, and the total number of prospective students talked to is four. This is precisely the cumulative reading. As we have seen, it can be true even if it is not the case that each of the professors talks to all the prospectives, therefore the second conjunct of (20) does not contradict (21).

In sum, Dowty's and Moltmann's proposal regarding the meaning of durative adverbials is compatible with cumulative readings, while Krifka's proposal is not, contrary to fact. We see that bringing the theories of aspect and quantification together has brought clarity on the meaning of an aspect-sensitive modifier which, on the face of it, has nothing to do with quantification. If we had only considered the proposed entries for "for an hour" in isolation, or if we had only applied them to nonquantificational noun phrases, we would have had one less argument that helps us choose among them.[9]

4   A unified account of nominal distributivity

In this section, we turn to distributivity in the domain of nominal quantifiers. We first review Landman (2000)'s theory of distributivity with two quantifiers (Section 4.1) and present the empirical landscape concerning distributivity with three quantifiers (Section 4.2). Based on proposals by Kratzer (1994, 1996)

Fig. 3), we could leave *four propectives* in low scope and use maximality conditions to ensure that the total of prospectives is four, following Zucchi and White (2001). We will return to this issue in the dissertation; see also fn. 19.

[9]Cleo Condoravdi (p.c.) notes that (15) may also have a reading in which at no single moment or over no single subinterval of the hour does the number of professors talking reach three, but rather what is affirmed is that the total number of professors talking over the course of the entire hour is three, and analogously for the four prospective students. This reading, if it can be confirmed with native speakers, would be a counterexample against the Dowty-Moltmann account, since it does not have the subinterval property. This question will be taken up for the dissertation.

and by Schein (1986, 1993), as well as new data, we argue that both external and internal arguments must be severed from their verbs, and reformulate Landman's system accordingly (Section 4.3). We then show how to generalize it to sentences with three quantifiers (Section 4.4). As a result, we obtain a novel treatment of so-called Schein sentences, a class of three-quantifier readings with high theoretical significance for event semantics (Schein, 1986, 1993). Durative adverbials will be brought back into the picture in the next section, where we will propose a single distributivity operator as part of the meaning of distributive nominal quantifiers as well as durative adverbials.

4.1 Distributivity in the case of two quantifiers

The following sentence illustrates a simple example of distributivity with two quantifiers:

(22) Three boys each invited four girls.

This sentence is true in a scenario where for each of the boys there is a potentially different set of four girls that he invites. A corresponding reading is of course also available as one of the readings of the same sentence without the overt distributivity marker *each* (23). We will call this reading the *subject distributive* reading or *distributive* reading for short:

(23) Three boys invited four girls.

We have already taken a brief look at Landman's theory in the previous section. We return to it in more detail now to see how it describes and derives the distributive reading. The theory presented in Landman, ch. 6, is concerned with deriving the interpretations of sentences with two upwards entailing quantifiers such as (23). Landman's representation for the distributive reading is shown in (24):

(24) $\exists X[{}^*\text{boy}(X) \wedge |X| = 3 \wedge \forall x\, [x \in AT(X) \rightarrow$
$\exists Y\, {}^*\text{girl}(Y) \wedge |Y| = 4 \wedge \exists e\, [{}^*\text{invite}(e)$
$\wedge {}^*\text{ag}(e) = x \wedge {}^*\text{th}(e) = Y]]]]$

This formula states that there exists a sum of three boys, and each of these boys is the agent of a potentially different inviting event (or sum of inviting events) whose plural theme is a sum of four girls. The expression $AT(X)$ returns the set of atomic parts of X, in this case the set of individual boys that make up X.

The theory presented in (Landman, 2000, ch. 6) derives both the cumulative and distributive reading of (23) as follows. Quantificational noun phrases (QNPs) like *three boys* are represented as generalized quantifiers over sums:[10]

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[10]To represent collective readings, Landman assumes that QNPs are systematically ambiguous between sums and groups. We ignore this for the moment since groups do not play a role in the readings we are interested in here.

(25) $[\![\text{three boys}]\!]_{\langle et,t \rangle} = \lambda P_{et}.\exists X_e \; [^{*}\text{boy}(X) \wedge |X| = 3 \wedge P(X)]$
— the set of all sets that contain a sum of three boys

For ease of exposition, we will write (25) somewhat simpler as follows, and we will simplify subsequent formulae accordingly:

(26) $[\![\text{three boys}]\!]_{\langle et,t \rangle} = \lambda P_{et}.\exists X_e \; [\text{three-boys}(X) \wedge P(X)]$

Verbs with valency n denote $n+1$-place predicates, with the event being the additional argument. For example, transitive verbs relate two individuals x and y and an event e:

(27) $[\![\text{invite}]\!]_{\langle e,\langle e,vt \rangle \rangle} = \lambda y_e.\lambda x_e.\lambda e_v.^{*}\text{invite}(e) \; \wedge \; ^{*}\text{ag}(e) = x \; \wedge \; ^{*}\text{th}(e) = y$

The predicate and the thematic roles are generalized to plural individuals and events by a "star" operator. For example, "*invite" is the closure of "invite" under sum, a predicate that is true of any inviting event or sum of inviting events. As we have seen before, "*ag" denotes a function that maps a sum of events to the sum of the agents of its atomic parts, and similarly for other roles.

The individual arguments of the verb are supplied by its syntactic arguments, and the event argument is bound off by existential closure. When one of the arguments is a QNP, it expects a property of individuals (type et), and the result is a type mismatch. Landman provides three mechanisms to resolve it: Either a type lifting rule is applied to the verb (or the VP) so that the QNP can be applied in situ, or the QNP is stored for later quantifying-in using one of two quantifying-in operations. Quantifying-in always happens above existential closure.[11] The type-lifting rules are called as needed a part of the application mechanism, but we show them in the figures as terminals for clarity. Two of them are needed for the derivations in this document. One, [lift-VP], is applied to VPs and to intransitive verbs; the other one, [lift-TV], is applied to transitive verbs. Each of them prepares its argument to apply to a QNP as opposed to an individual-denoting noun phrase (see Fig. 1 for an example):

(28) $[\![[\text{lift-VP}]]\!]_{\langle \langle e,vt \rangle,\langle \langle et,t \rangle,vt \rangle \rangle} = \lambda V_{\langle e,\langle e,vt \rangle \rangle}.\lambda Q_{\langle et,t \rangle}.\lambda x_e.\lambda e_v.Q[\lambda y_e.V(y)(x)(e)]$

(29) $[\![[\text{lift-TV}]]\!]_{\langle \langle e,\langle e,vt \rangle \rangle,\langle \langle et,t \rangle,\langle e,vt \rangle \rangle \rangle} = \lambda R_{\langle e,vt \rangle}.\lambda Q_{\langle et,t \rangle}.\lambda e_v.Q[\lambda x_e.R(x)(e)]$

The two quantifying-in operations NQI and SQI work as follows.

NQI or non-scopal quantifying-in corresponds to classical Montague quantifying-in, which is equivalent to quantifier raising (QR) as presented e.g. in Heim and Kratzer (1998). Roughly, NQI takes a QNP q that is just about to be entered in the thematic role θ (say, the agent) of a VP v and asserts that the plural entity denoted by q is the plural agent of the event denoted by v. Landman calls this operation non-scopal because by itself it does not

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[11]Landman also discusses a third operator, DQI, which is like SQI except that before it applies to a group QNP, it demotes it to a sum. He does not end up using it because he instead assumes that QNPs are ambiguous between group and sum interpretations.

create any scopal dependencies between QNPs. This is so because, as we have seen, QNPs are all represented with existential quantifiers, and in the absence of other quantifiers, these quantifiers are scopally commutative – their relative order does not affect the truth conditions of a formula. I will not demonstrate NQI because it is no different from run-of-the-mill QR. NQI is not used much in Landman's system, and we will not use it in any of the derivations showcased in this proposal.

SQI or scopal quantifying-in raises the QNP and adds a universal quantifier over every one of its atoms. We can therefore regard SQI as the combination of QR with a distributivity operator, call it [dist], a function from generalized quantifiers to generalized quantifiers. This operator is applied to the raised QNP before it is applied to the lambda abstract denoting the rest of the sentence.

(30) $[\![\text{dist}]\!]_{\langle\langle et,t\rangle,\langle et,t\rangle\rangle} = \lambda Q_{\langle et,t\rangle}.\lambda P_{et}.Q(\lambda y_e.\forall x \ [x \in AT(y) \rightarrow P(x)])$

This operator takes a QNP Q and a property P and asserts that Q holds of the property that is true of any individuals that contains only atoms to which P applies. (Recall that $AT(y)$ denotes the set of all the atoms of y.) To make this more concrete, here is the result of applying [dist] to (26), the entry for *three boys*:

(31) $[\![\text{dist}]\!]([\![\text{three boys}]\!])_{\langle et,t\rangle}$
       $= \lambda P_{et}.\exists X_e \ \text{three-boys}(X) \wedge \forall x \ [x \in AT(X) \rightarrow P(x)]$

(26) is true of any property of individuals that applies to each atom in a sum of three boys. That is, it takes a property and asserts that there are three boys and that the property applies to each of them.

An example of [dist] is shown in Fig. 4. That figure is a derivation of the distributive reading of (23) shown above in (24).

4.2   Distributivity in the case of three quantifiers

Landman's theory has been designed to account for cumulativity and distributivity in sentences with two quantifiers. In these sentences, distributivity and cumulativity can never both occur at the same time: Either the two quantifiers stand in a cumulative relation, or one distributes over the other. In a sentence with three quantifiers, however, one would expect that distributivity and cumulativity can both occur, with two quantifiers standing in a cumulative relation, and the third standing in a distributive relation with one of the two. As we will see in this section, such readings indeed exist, but Landman's system, as it has been presented so far, does not generalize well to this case.

Here is why Landman's system could run into trouble. Following Schein's observation, Landman establishes cumulative relations between quantifiers via the meaning of the verb. That is, by closing the verb meaning under sum, he generalizes the it to the case where its arguments stand in a cumulative relation. A cumulative relation between two QNPs is established by leaving both of them

in situ. A QNP like *three boys* is entered into a cumulative relation by asserting that the sum of three boys is the plural agent (or patient, etc.) of the verb.

By contrast, a distributive relation between two QNPs is established by raising one of them over the other using SQI. This operation causes the QNP to distribute over the rest of the sentence. It also prevents it from entering a cumulative relation with another quantifier. To understand why this is so, consider again (31), repeated here as (32). This is the QNP *three boys* as it looks after it has been raised with SQI, an operation which applies [dist] to it:

(32) $[\![\text{dist}]\!]([\![\text{three boys}]\!])_{\langle et,t \rangle}$
     $= \lambda P_{et}.\exists X_e \; [\text{three-boys}(X) \wedge \forall x \; [x \in AT(X) \rightarrow P(x)]]$

In this expression, the variable X represents the sum of three boys, and the variable y ranges over the individual boys. This expression takes only one argument, indicated by λP, and applies it to y, not to X. That is, the argument can assert something only about the individual boys, but not about the sum of boys. But to enter *three boys* into a cumulative relation according to Landman's way of doing things, we need to assert something about that sum of boys, namely, that it is the plural agent or patient of the verb.

Now imagine the following situation: You have a verb with three arguments A, B, and C. All of them are QNPs. Two of them, say A and B stand in a cumulative relation. In addition, B distributes over C. To cause B to distribute over C, we need to apply SQI to it, but this will prevent it from entering a cumulative relation with A. Does this kind of reading exist? The answer is yes, as shown by sentence (33), taken from (Landman, 2000, ch. 10):

(33) Three boys gave six girls two flowers each.

The relevant reading of this sentence is the one in which some boys gave some girls some flowers, such that the total number of boys involved is three, the total number of girls involved is six, and each girl received two flowers, i.e. the total number of flowers is up to twelve. Here, A is three boys, B is six girls, and C is two flowers.

As before, the word *each* favors this reading but is not necessary to produce it:

(34) Three boys gave six girls two flowers.

Landman is aware that his system, as described so far and in his ch. 6, does not generate these sentences. The last chapter of Landman (2000) is devoted to them in its entirety. The system in that chapter is not intended to replace the one in his ch. 6 but is instead added on to it. We will review it in detail in the dissertation; in this proposal, we are interested in generalizing distributivity across both the two-quantifier and the three-quantifier case. For this purpose, we will first establish the correct logical representation of the meaning of (34), and second, provide a compositional way of deriving it.

The first task has already been accomplished by Schein (1986, 1993), who provides an extensive argument in favor of the following representation:

(35) $\exists E \; \exists X$ three-boys$(X) \; \wedge \; ^*$ag$(E) = X \; \wedge$
$\quad \exists Y$ six-girls$(Y) \; \wedge \; \forall y \; [y \in AT(Y) \rightarrow$
$\quad \exists e \leq E[^*$give$(e) \; \wedge \; ^*ben(e) = y \; \wedge \exists Z$ two-flowers$(Z) \; \wedge ^*$th$(e) = Z]]$

This formula states that there is a sum of events E whose agents total three boys, and there are six girls, each of whom is the beneficiary of a giving subevent of E whose theme is a sum of two flowers.

There is an important feature that distinguishes this formula from all others we have seen so far. Namely, the verbal predicate *give and the thematic roles *ag, *ben and *th do not all apply to the same event variable: *ag applies to E and the others apply to e. Schein calls this phenomenon *essential separation* and takes considerable care to show that it is not a notational artifact but, as he claims, an essential feature of any representation formalism suitable for expressing natural language. According to Schein, modeling essential separation requires a logical language that makes explicit reference to events, and is therefore a strong theoretical argument for event semantics.[12]

To generate this kind of "Schein reading", we will introduce into Landman's system an operator on thematic roles that performs two tasks: First, like SQI, it causes any QNP that combines with that role distribute over everything below it; second, it separates any thematic roles above the QNP from the verb below the QNP. Before we can do that, though, we need to separate the thematic roles from their verbs so that essential separation becomes possible.

4.3   How much essential separation is needed?

Landman associates verbs and their thematic roles in the lexicon, as can be seen in (27), repeated here as (36):

(36) $\llbracket$invite$\rrbracket_{\langle e, \langle e, vt \rangle \rangle} = \lambda y_e . \lambda x_e . \lambda e_v . ^*$invite$(e) \; \wedge \; ^*ag(e) = x \; \wedge \; ^*th(e) = y$

In this entry, the verbal predicate *invite and the thematic role *ag are applied to the same event argument e. This is not what we need. To make essential separation possible, we need to separate at least the role of the external argument, *ag, into another entry. This argument has also been made by Kratzer (1994, 1996), who argues that this is the appropriate way to capture asymmetries between the external and the internal argument. Whether we also need to separate the other thematic roles, in particular, the internal argument, is a difficult question. Kratzer herself did not succeed in extending Schein's argument to other roles. As we have seen, in a Schein sentence, the argument that undergoes essential separation is the one that takes part only in the cumulative relation but not in the distributive relation. In our schema above, we have called it argument A. Can we find a sentence in which argument A is the internal argument? It seems that the answer is yes:

(37) Two treaties were signed with a personalized pen by six diplomats.

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[12]But see Beck and Sauerland (2000).

According to some native speakers, this sentence has a reading in which a total of six diplomats signs a total of two treaties and the total number of pens used is six.[13] In other words, *two treaties* and *six diplomats* stand in a cumulative relation, and *six diplomats* distributes over *a personalized pen*. This means that argument A in this sentence is the internal argument, *two treaties*. It follows that the thematic roles not only of external but of internal arguments must be introduced by a separate λ expression.[14]

Which lexical items introduce thematic roles? We will not explore this question in detail here since it is not our main concern, but simply follow Kratzer (1994, 1996) and much recent Minimalist work and stipulate abstract heads. For the external argument, we will identify this head with little v; for all other arguments and adjuncts, we will use identify them with prepositions (covert ones in the case of the internal argument). Alternatively, we could also think of the verb's semantics being represented by a set of expressions, similar to e.g. the decompositional semantics of *how many* (Cresti, 1995; Scheffler, 2004). A similar approach will be used in Section 6 when we will provide a syntax-semantics interface using Tree-adjoining Grammar, a grammar formalism whose extended domain of locality causes the lexical entries for verbs to contain their thematic roles.)

Having established the need for separating thematic roles, we are led to the conclusion that the distinction between arguments and adjuncts is either a purely syntactic one, or at any rate, it is not encoded on the semantic side of the lexical entry of a verb. Therefore, noun phrases with their thematic roles must act as modifiers on the verb. Our official entry for a verb like *invite* is a function that is true of any sum of inviting events:

(38) $[\![\text{invite}]\!]_{vt} = \lambda e_v.^*\text{invite}(e)$

Concerning the role of the inner argument, we can either continue to assume that the denotation of its noun phrase is of type e, and lift the role's entry if necessary, as Landman does it; or we could apply the type-lift in the lexicon to all role heads and to all noun phrases of type e, in the tradition of Montague (1974). We have this choice because in Landman's system, type-lifting applied to nonterminals such as VPs as part of the compositional process, but in our system, it always applies to thematic roles, and thematic roles are now terminals. How we decide on this question is immaterial; for ease of comparison, we will continue to apply it as part of the compositional process. As for the thematic relation itself, we can either make it verb-specific, such as *invitee*, or general,

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[13]I am indebted to Aviad Eilam and Josh Tauberer for native judgments and for discussion on this example. For some native speakers, the relevant reading is not available, while for others, it is only available (or more readily available) when the PP is at the end of the sentence: *Two treaties were signed by six diplomats with a personalized pen.* A larger sample would of course be desirable. An experiment using a platform like WebExp2 (Keller et al., 1998; Mayo et al., 2005) or similar software could be run for the dissertation.

[14]Schein (1993) arrives at the same conclusion. Kratzer (1994) notes that his argument is based on examples involving separation on the external argument and does not generalize to other cases, and tries – but ultimately fails – to find counterexamples like (37).

such as *theme.* See Kratzer (1994, 1996); Schein (2002) for discussion on this question. For our purposes, the choice is immaterial as well, and again we will follow Landman and use *theme.* Since full noun phrases act as modifiers on the verb, thematic roles must be functions from individuals to verb modifiers. Our inner role's entry is therefore the function that takes a sum individual x and a property of events f and adds to that property the requirement that if the individual is the plural theme of any events f applies to. For the indirect object of *give,* we will use an abstract head [ben] for beneficiary[15] Prepositions are treated similarly:

(39) $[\![\text{[theme]}]\!]_{\langle e, \langle vt, vt \rangle \rangle} = \lambda x_e . \lambda f_{vt} . \lambda e_v . f(e) \wedge {}^*\text{th}(e) = x$
  $[\![\text{[ben]}]\!]_{\langle e, \langle vt, vt \rangle \rangle} = \lambda x_e . \lambda f_{vt} . \lambda e_v . f(e) \wedge {}^*\text{ben}(e) = x$
  $[\![\text{in}]\!]_{\langle e, \langle vt, vt \rangle \rangle} = \lambda x_e . \lambda f_{vt} . \lambda e_v . f(e) \wedge {}^*\text{in}(e) = x$
  $[\![\text{at}_{temporal}]\!]_{\langle e, \langle vt, vt \rangle \rangle} = \lambda t_e . \lambda f_{vt} . \lambda e_v . f(e) \wedge {}^*\tau(e) = t$
  — etc.

Our type lifter prepares the thematic role H for accepting a QNP Q (of type $\langle et, t \rangle$) instead of an individual:

(40) $[\![\text{[lift]}]\!]_{\langle \langle e, \langle vt, vt \rangle \rangle, \langle \langle et, t \rangle, \langle vt, vt \rangle \rangle \rangle}$
  $= \lambda H_{\langle e, \langle vt, vt \rangle \rangle} . \lambda Q_{\langle et, t \rangle} . \lambda f_{vt} . \lambda e_v . Q[\lambda x_e . H(x)(f)(e)]$

As an example, lifting the theme head gives the following result:

(41) $[\![\text{[lift]}]\!]([\![\text{[theme]}]\!])_{\langle \langle et, t \rangle, \langle vt, vt \rangle \rangle}$
  $= \lambda Q_{\langle et, t \rangle} . \lambda f_{vt} . \lambda e_v . Q[\lambda x_e . f(e) \wedge {}^*\text{th}(e) = x]$

Concerning the external argument, for syntactic reasons, little v takes the verb in its complement and the noun phrase in its specifier, as opposed to prepositions where it is the other way round. So little v combines first with a property of events and then with an individual. Otherwise, the entry looks the same:[16]

(42) $[\![\text{[v]}]\!]_{\langle vt, \langle e, vt \rangle \rangle} = \lambda f_{vt} . \lambda x_e . \lambda e_v . {}^*\text{ag}(e) = x \wedge f(e)$

Because of this asymmetry, we need a separate type-lifter. As it happens, we can recycle one of the type-lifters from Landman's original system:

(43) $[\![\text{[lift-}v'\text{]}]\!] = [\![\text{[lift-VP]}]\!]_{\langle \langle e, vt \rangle, \langle \langle et, t \rangle, vt \rangle \rangle}$
  $= \lambda R_{\langle e, vt \rangle} . \lambda Q_{\langle et, t \rangle} . \lambda e_v . Q[\lambda x_e . R(x)(e)]$

[lift-v'] applies to v', the projection of little v, and prepares it for receiving a QNP instead of an individual from its specifier.

A sample derivation is shown in Fig. 5.

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[15]In the dissertation, we will figure out if [ben] should follow the syntactic layout of little v or that of a preposition.

[16]See Kratzer (1996) for arguments for an alternative mode of composition that uses an operation called event identification. Here, for simplicity, we only use beta reduction. In the dissertation, we will compare the two modes of composition and arguments for either side. Also, we will consider to what extent the syntactic reasons for this asymmetry are plausible. Without going into detail here, binding theory arguments seem of limited relevance because of left-edge effects: NPs that are embedded in the subject of a sentence seem to behave as if they c-command the VP (Kayne, 1994).

4.4 Generalizing Landman to the three-quantifier case

Now that we have prepared the grammar for essential separation, we will now introduce into Landman's system an operator on thematic roles that fulfills the required purpose: First, like SQI, it should cause any noun phrase that combines with that role to distribute over everything below it; second, it should separate any thematic roles above the noun phrase from the verb below it. We will call our operator [sepdist$_{QNP}$], to suggest that it introduces both essential separation and distributivity into the derivation. The subscript indicates that it is intended for use with QNPs only; we will generalize it to durative adverbials in Section 5. It would be possible to write [sepdist$_{QNP}$] so that it expects a noun phrase of type e, and to type-lift it so that it can accept a QNP. For ease of exposition, and because it appears redundant to write a type lifter for a single lexical entry, we will instead lift the type of [sepdist$_{QNP}$] directly in the lexicon, and assume that the lifting happens instead on any noun phrases of type e that combine with it. Here is our entry:

(44) $[\![\text{sepdist}_{QNP}]\!]_{\langle\langle e,\langle vt,vt\rangle\rangle,\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle\rangle}$
    $= \lambda H_{\langle e,\langle vt,vt\rangle\rangle}.\lambda Q_{\langle et,t\rangle}.\lambda f_{vt}.$
    $\lambda e_v.Q(\lambda y_e.\forall x\ [x \in AT(y) \rightarrow \exists e'[e' \leq e \wedge H(x)(f)(e')]])$

[sepdist$_{QNP}$] takes a thematic role head H, a QNP Q, and a property of events f (usually supplied by a verb or verb phrase). It returns a property that is true of any sum e of events such that for every atomic part y of the individual x bound by the quantifier, there is a part of e that stands in the relation H to y.

As an example, here is the result of combining [sepdist$_{QNP}$] first with [ben] ...

(45) $[\![\text{sepdist}_{QNP}]\!]([\![\text{ben}]\!])_{\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle}$
    $= \lambda Q_{\langle et,t\rangle}.\lambda f_{vt}.\lambda e_v.Q(\lambda y_e.\forall x\ [x \in AT(y) \rightarrow$
    $\exists e'[e' \leq e \wedge f(e') \wedge {}^*\text{ben}(e') = x]])$

...and then with *six girls*:

(46) $[\![\text{sepdist}_{QNP}]\!]([\![\text{ben}]\!])([\![\text{six girls}]\!])_{\langle vt,vt\rangle}$
    $= \lambda f_{vt}.\lambda e_v.\exists X\ \text{six-girls}(X) \wedge \forall x\ [x \in AT(X) \rightarrow$
    $\exists e'[e' \leq e \wedge f(e') \wedge {}^*\text{ben}(e') = x]]$

The function denoted by (46) takes any property f of events and returns the property that is true of any event e for which there are six girls who each are the beneficiary of a subevent of e to which f applies.

As we have seen in the previous subsection, we have chosen to identify our agent head with little v, and syntactic theory tells us that the order of its arguments is inverted, so that it has a different type than the other role heads. So we again need a slightly different entry for [sepdist$_{QNP}$] that applies to vP. Again, the fact that we need two almost identical operators is syntactically motivated by the fact that specifier and complement of little v are inverted

compared to other thematic heads, and it is not a shortcoming of the semantic theory. Here is the entry:

(47) $[[\text{sepdist}_{QNP}']]_{\langle\langle e,vt\rangle,\langle\langle et,t\rangle,vt\rangle\rangle}$
      $= \lambda R_{\langle e,vt\rangle}.\lambda Q_{\langle et,t\rangle}.$
      $\lambda e_v.Q(\lambda y_e.\forall x\ [x \in AT(y) \rightarrow \exists e'[e' \leq e \wedge R(x)(e')]])$

As demonstrated in Fig. 6, [sepdist$_{QNP}$] indeed derives the correct representation (35) for sentence (34), as desired. They are repeated here as (48):

(48) Three boys gave six girls two flowers.
      $\exists E\ \exists X\ \text{three-boys}(X)\ \wedge\ ^*\text{ag}(E) = X\ \wedge$
      $\exists Y\ \text{six-girls}(Y)\ \wedge\ \forall y[y \in AT(Y) \rightarrow$
      $\exists e \leq E[^*\text{give}(e)\ \wedge\ ^*\text{ben}(e) = y\ \wedge \exists Z\ \text{two-flowers}(Z)\ \wedge ^*\text{th}(e) = Z]]$

But the [sepdist$_{QNP}$] operator is not only useful for deriving Schein readings. It can also be used in place of Landman's SQI to establish a distributive relation between two quantifiers regardless of whether a third is present. In that case, the event variable e it introduces is not modified by a third quantifier but simply bound off by existential closure. This is exemplified in Fig. 7. In this figure, [sepdist$_{QNP}'$] is used to derive the surface distributive reading (24) of (23), repeated here as (49):

(49) Three boys invited four girls.
      $\exists X[\text{three-boys}(X) \wedge \forall x\ [x \in AT(X) \rightarrow$
      $\exists Y[\text{four-girls}(Y) \wedge \exists e\ [^*\text{invite}(e)$
      $\wedge^*\text{ag}(e) = x \wedge ^*\text{th}(e) = Y]]]]$

As Fig. 7 shows, the representation resulting from the use of [sepdist$_{QNP}'$] is not exactly the one in (49), but rather this one:

(50) $\exists E\ \exists X[\text{three-boys}(X) \wedge \forall x\ [x \in AT(X) \rightarrow$
      $\exists Y[\text{four-girls}(Y) \wedge \exists e[^*\text{invite}(e)\ \wedge\ e \leq E$
      $\wedge^*\text{ag}(e) = x \wedge ^*\text{th}(e) = Y]]]]$

This reading expresses that there exist a sum of events E and a sum of three boys, and each of these boys is the agent of a different inviting subevent of E whose theme is a sum of four girls.

However, this formula is truth-conditionally equivalent to (49). To see this, note that nothing at all is predicated of the sum event E except that the events over which the variable e ranges are parts of it. But, by the assumptions of our model theory, events are closed under sum, no matter which events e ranges over, there will always be a sum of events that has all of them as a part. Therefore, the existential quantifier $\exists E$ is vacuous, so the two formulas are equivalent.

At this point, we have almost succeeded in unifying the two cases of distributivity between quantifiers that we have encountered. The only case we have not yet discussed is the case of distributivity under inverse scope, that is, a quantifier distributes over another quantifier that c-commands it at surface structure.

However, even this case can be brought under the umbrella of [sepdist$_{QNP}$] if we assume a mechanism that delays the application of a QNP and its thematic role until another QNP has applied. The mechanism we need is different from Quantifying-In or Quantifier Raising because it does not leave a trace behind – in fact, we are free to regard it either as traceless movement or as the application of a delaying operator, as described in Hendriks (1993), for example. In Fig. 8, the former option is used. A similar mechanism is also argued for by Beaver and Condoravdi (2007), whose remarks apply to the present system in full:

> The advantages of [the system] for a free word-order language with morphological case marking should be obvious. But even for English the advantages are substantial: (i) verbal alternations (like the dative alternation) as well as valency changes can be analysed without postulating an underlying verbal ambiguity, (ii) quantifiers can be analyzed in situ without boosting verb types unnaturally ...

Since we do not need SQI anymore, we can drop it from our system. Can we actually drop all Quantifying-in? Landman's only other operator, NQI, is never actually used in his system except in one case to derive branching readings (p. 209), but he later derives branching readings by other means (ch. 9). So as far as the data in this proposal is concerned, we can remove all quantifying-in from the system and replace it with a traceless movement operation of our choice.[17]

We will provide a more detailed comparison of the present system with Beaver and Condoravdi (2007)'s system in the dissertation. For now, let us summarize the results of this section. Besides demonstrating that essential separation is necessary both for the external (as noted by Kratzer (1996)) and for the internal argument, we have shown that distributivity in Schein sentences can be reduced to the same operator as distributivity in the two-quantifier case. Thus equipped with a novel distributivity operator, we now return to durative adverbials.

5 A unified account of nominal and adverbial distributivity

This section is the centerpiece of this proposal. We show that there is a close connection between the generalized distributivity operator we have obtained in the previous section, and the distributive part of the meaning of durative adverbials we have obtained in Section 3. We start in Section 5.1 by decomposing durative prepositions into a thematic head and a distributivity operator, which turns out to be practically identical to the one we had obtained in the previous

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[17]Quantifying-in or QR will still have a role in the grammar overall. It will continue to be needed for long distance dependencies such as LF movement across clauses, where the thematic role head needs to remain in situ in order to record which verb the moved noun phrase modifies, as well as for inverse linking cases. Also, we have considered QR as one option to prevent *for*-phrases from distributing over a QNP, see fns. 8 and 19.

section. In Section 5.2, we provide independent evidence for this decomposition, and explore the option of unifying distributivity across both domains.

5.1 Isolating distributivity in durative adverbials

First, let us go back to the issue of durative adverbials. In Section 3, we had seen that Krifka's entry for *for an hour* (10) is not compatible with cumulative readings, unlike the Dowty/Moltmann entry (14), which is repeated here as (51):

(51) $[\![\text{for an hour}_{Dowty/Moltmann}]\!]_{\langle\langle v,et\rangle,et\rangle}$
$= \lambda R_{\langle v,et\rangle} \lambda x_e. \exists t\,[H(t)=1]$
$\wedge\, \forall t'\,[t'\mathrm{P}t \to \exists e\,[R(e,x) \wedge \tau(e)=t']]$

This entry expects a VP argument R and a subject argument x. R is of type $\langle v,et\rangle$ here (it expects an event and an individual, corresponding to the agent). This needs to be revised in light of the previous section, where we have seen that we have to separate the arguments from the lexical entry of the verb. This caused the VP and verbal projections in general to be of type vt, while the subject noun phrase including its thematic role will be of type $\langle vt,vt\rangle$. The corresponding changes to (51) result in the following:

(52) $[\![\text{for an hour}_{rev1}]\!]_{\langle vt,\langle\langle vt,vt\rangle,t\rangle\rangle}$
$= \lambda f_{vt} \lambda N_{\langle vt,vt\rangle}. \exists t\,[H(t)=1]$
$\wedge\, \forall t'\,[t'\mathrm{P}t \to \exists e\,[N(f)(e) \wedge \tau(e)=t']]$

Unfortunately, there is one potential problem with this entry: it forces the subject, N, to have low scope compared with the universal quantifier over times. We will fix this problem in a moment, along with another disadvantage, which was already shared by our original entry (51): It only distributes the subject and VP over all events that take place at relevant subintervals of the hour interval, but does not make a available a single sum event. This would predict that it is impossible to refer to this sum event. But this prediction is not borne out. The following counterexample is taken from (Schein, 1993), who credits Taylor (1985) and Davies (1991) with similar examples:

(53) Unharmoniously, every organ student sustained a note on the Wurlitzer for sixteen measures.

As Schein notes (p. 99),

> [this sentence] reports that the ensemble event was unharmonious and not any one student's note. ...But to assert that each student sustained his own note while attributing disharmony to the collective performance requires quantification over the parts of the larger event ...

Intuitively, *for sixteen minutes* delimits the entire event – the same event that is modified by *unharmoniously*. We therefore modify our previous entry to include reference to a larger event of which the smaller events are parts. The modifications are shown in boldface:

(54) $[\![$for an hour$_{rev2}]\!]_{\langle vt, \langle \langle vt, vt \rangle, vt \rangle \rangle}$
$= \lambda f_{vt} \lambda N_{\langle vt, vt \rangle} \lambda \mathbf{e_v}. \exists t \ [H(t) = 1]$
$\wedge \ \forall t' \ [t'\mathrm{P}t \rightarrow \exists e' \ [\mathbf{e'} \leq \mathbf{e} \wedge N(f)(e') \wedge \tau(e') = t']]$

It may seem that we should relate t to e directly by asserting e.g. that $\tau(e) = t$. But this will generally be redundant: It is reasonable to assume that P, the contextually supplied function which picks out relevant subintervals, is such that every point in t is the point of some relevant subinterval of t. We will refer to this condition as saying that P is a *partition* of t. Given this, we can show that the runtime of e is at least one hour.[18]

Now that we have introduce the e (we will call it the *outer event*), we can apply modifiers like *unharmoniously* to it. But as we have seen in the previous section, essential separation causes nominal arguments including the subject to behave semantically like modifiers. So we can drop the reference to the subject from our entry, since it will be able to modify the outer event just as *unharmoniously* will.[19] Here is the resulting entry:

(55) $[\![$for an hour$_{rev3}]\!]_{\langle vt, vt \rangle}$
$= \lambda f_{vt} \lambda e_v. \exists t \ [H(t) = 1]$
$\wedge \ \forall t' \ [t'\mathrm{P}t \rightarrow \exists e' \ [e' \leq e \wedge f(e') \wedge \tau(e') = t']]$

Throughout this document we have talked of *for an hour* as a single unit, and given lexical entries for it as if it were an idiom. But of course this is not so, so let us decompose it. First, we will isolate *an hour*. Intuitively, we expect *an hour* to be a generalized quantifier over time intervals, just like *a boy* is a generalized quantifier over individuals. Assuming that the function H from times to numbers is only defined on time intervals, we don't actually have to use the type system to state that restriction and can represent it as a generalized

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[18]A proof will be added in the dissertation. Partitions are a special case of covers in the sense of Schwarzschild (1991, 1996), and this link to will be explored in depth. It might turn out that I have retraced part of the way that Schwarzschild has gone, although I start from indefinite quantifiers and he starts from definites ones. Also, using the right set of mereological assumptions – e.g. Krifka (1998) – it is not necessary that t be convex. This opens the door to a treatment of iterative sentences that could improve on van Geenhoven (2004, 2005) by not requiring the postulation of separate iterativity operators. This will be taken up in the dissertation.

[19]Alternatively, we could rewrite the entry so that the subject modifies the inner event e' but has wide scope. We could also leave the entry unchanged but treat *for an hour* as an IP modifier or adopt the VP-internal subject hypothesis, so that the subject starts out within its scope, and use QR to move the subject out should this be necessary (but see Zucchi and White (2001) against such an option, who do not consider cases of cumulative quantification, however). Access to the inner event may be necessary for bare plural subjects. All these options have different syntactic and semantic consequences and will be explored in the dissertation. See also fn. 8.

quantifier over individuals. For ease of exposition, we will nonetheless continue to use t to indicate that the individual's values will end up being times:

(56) $[\![\text{an hour}]\!]_{\langle et,t\rangle} = \lambda P_{et}.\exists t_e\ H(t) = 1\ \wedge\ P(t)$

Given (55), this leaves us with only one choice for *for*:

(57) $[\![\text{for}]\!]_{\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle}$
$= \lambda Q_{\langle et,t\rangle}\lambda f_{vt}\lambda e_v.Q(\lambda t_e.\forall t'\ [t'\mathrm{P}t \rightarrow$
$\exists e'[e' \leq e \wedge f(e') \wedge \tau(e') = t']])$

Now let us compare this entry with (45), the result of applying $[\text{sepdist}_{QNP}]$ to a thematic role, in this case [ben]. (45) is repeated here as (58):

(58) $[\![[\text{sepdist}_{QNP}]]\!]([\![[\text{ben}]]\!])_{\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle}$
$= \lambda Q_{\langle et,t\rangle}.\lambda f_{vt}.\lambda e_v.Q(\lambda y_e.\forall x\ [x \in AT(y) \rightarrow$
$\exists e'[e' \leq e \wedge f(e') \wedge\ ^*\text{ben}(e') = x]])$

Lines (57) and (58) look almost identical, suggesting a strong similarity between $[\text{sepdist}_{QNP}]$ and *for*. To make the similarity clearer, we can decompose the entry of *for* along the lines of (58) into a thematic head, which we may call [time], and a distributive operator, which is called $[\text{sepdist}_{for}]$ here. For comparison, they have been juxtaposed with the entries for [ben] and $[\text{sepdist}_{QNP}]$, repeated from (39) and (44) above:

(59) $[\![[\text{time}]]\!]_{\langle e,\langle vt,vt\rangle\rangle}\ = \lambda t_e.\lambda f_{vt}.\lambda e_v.f(e) \wedge \tau(e) = t$

(60) $[\![[\text{ben}]]\!]_{\langle e,\langle vt,vt\rangle\rangle}\ \ = \lambda x_e.\lambda f_{vt}.\lambda e_v.f(e) \wedge\ ^*\text{ben}(e) = x$ $\hspace{2cm}(= 39)$

(61) $[\![[\text{sepdist}_{for}]]\!]_{\langle\langle e,\langle vt,vt\rangle\rangle,\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle\rangle}$
$= \lambda H_{\langle e,\langle vt,vt\rangle\rangle}.\lambda Q_{\langle et,t\rangle}.\lambda f_{vt}.$
$\lambda e_v.Q(\lambda t_e.\forall t'[t'\mathrm{P}t \rightarrow \exists e'[e' \leq e \wedge H(t')(f)(e')]])$

(62) $[\![[\text{sepdist}_{QNP}]]\!]_{\langle\langle e,\langle vt,vt\rangle\rangle,\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle\rangle}$ $\hspace{2cm}(= 44)$
$= \lambda H_{\langle e,\langle vt,vt\rangle\rangle}.\lambda Q_{\langle et,t\rangle}.\lambda f_{vt}.$
$\lambda e_v.Q(\lambda y_e.\forall x\ [x \in AT(y) \rightarrow \exists e'[e' \leq e \wedge H(x)(f)(e')]])$

Keep in mind that the use of letters x, y and t, t' is only for clarity of exposition (since we do not use a sortal distinction to track the difference between times and (other) individuals in the logic, the letters are interchangeable). Then the only difference between [time] and [ben] is the function that maps events to individuals – τ in one case, *ben in the other. Note that the fact that only one of them is pluralized is not a relevant difference, since $\tau = {}^*\tau$. This is a consequence of the fact that τ is a homomorphism, $\tau(e) \oplus \tau(e') = \tau(e \oplus e')$[20] Therefore, [time] and [ben] differ no more from each other than any two thematic role heads.

The only difference between $[\text{sepdist}_{for}]$ and $[\text{sepdist}_{QNP}]$ is the nature of the relation P. In one case, it is left free to be contextually supplied, in the other case, it is instantiated as $\lambda y\lambda x.y \in AT(x)$. I will refer to this latter relation as *is-atom-of*.

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[20]A proof of this fact will be included in the dissertation.

5.2 Evidence for the decomposition of durative adverbials

It is easy to decompose lexical entries, so before we carry on with this "sublexical semantics", we need to make sure that we are not just splitting up the meaning of *for* into two operators that are not otherwise attested. After all, there is no phonological or syntactic evidence that *for* is the merger of two lexical items. As it turns out, there is evidence for the independent existence of both these items.

First, consider [time]. This operator takes a time interval and a set of events and intersects that set with the set of events that happen at that time interval. This is just the meaning of the temporal preposition *at*, as in *at noon*, *at 2pm* and so on. We have noted in Section 4.3 that prepositions and thematic roles have the same semantic type, and their entries follow the same general format. It follows that [time] is just a silent form of the word *at*.

Now consider [sepdist$_{QNP}$] and [sepdist$_{for}$]. Suppose we can unify the two, i.e. drop one from the system and use the other instead of it. Then the arguments for the existence of [sepdist$_{QNP}$] in Section 4.4 constitute independent evidence for the existence of this operator, call it [sepdist] (without subscript). So can we unify them?

We cannot use [sepdist$_{for}$] in durative adverbials instead of [sepdist$_{QNP}$] because the relation *is-atom-of* is not necessarily defined on times – indeed, in Krifka's theory, nothing forces us to assume that time is atomic. Even if other linguistic reasons end up leading us to assume that time is atomic, these atoms would in many cases still be too small to be relevant to a *for* adverbial, and we would not be able to cope with the minimal parts problem (see Section 5).

So let us see instead if we can use [sepdist$_{for}$] instead of [sepdist$_{QNP}$]. To do this, we need to check two things: (i) that *is-atom-of* is compatible with the constraints on possible values of P, and (ii) that P can take on other values than *is-atom-of* in nominal contexts (otherwise [sepdist$_{for}$] would overgenerate in these contexts). With respect to (i), we have established in Section 5 that P must be a partition, and since every object is equal to the sum of its atomic parts, *is-atom-of* is a partition. With respect to (ii), we need to check if there are distributive readings in which the distributivity does not range over all the atomic parts of a noun phrase but also over some of its nonatomic parts. This is indeed the case, as is well known in the literature on definite plurals (Schwarzschild, 1991, 1996, and others):

(63) The boys built a raft.

Sentence (63) has a reading in which more than one raft is built, indicating that *the boys* distributes over *a raft*. But it is vague with respect to how many rafts are built. For example, it could be the case that the boys form two groups or teams, and that each team built a raft. In this case, two rafts are built, even though there may be more than two boys. We can find similar examples involving indefinite plurals:

(64) Three Dutch professors received a Nobel prize in linguistics.

Suppose that the following Dutch professors received a prize: Jeroen Groenendijk and Martin Stokhof received a prize for their joint dissertation, Groenendijk and Stokhof (1984), and Johan van Benthem received a prize for his life's work. In total, only two linguistics prizes were awarded. According to native speakers, (64) is true in this scenario. Jeroen Groenendijk and Martin Stokhof received a prize as a group, i.e. collectively, and we have set collective interpretations aside for this document, but suffice it to say that either (i) the sum over which the QNP *three Dutch professors* quantifies contains among its atoms some groups of professors as well as single professors, or (ii) [sepdist] does not, in fact, distribute down to atoms. That (i) is not a viable option can be seen by looking at (65), in analogy to a similar argument by Schwarzschild (1991) involving definite plurals:

(65)   Three Dutch professors received a Nobel prize in linguistics and smiled during the ceremony.

For at least some native speakers, this sentence has a reading in which two of the Dutch professors jointly got a prize (and the third one got another prize by himself), and each of the three professors smiled during the ceremony. Without going into details about the semantics of coordination, the second conjunct needs to access the atoms in the sum over which the QNP quantifies. Intuitively, the VP *smiled* applies only to humans and perhaps their sums, but certainly not to groups or sums of groups – it is not possible to say **The committee smiled*, for example.[21] This leaves only (ii) as an option – [sepdist] does not distribute down to atoms. At the same time, it is clear that [sepdist] must distribute over all three professors, either individually or as part of a group. But this is identical to requiring that [sepdist] must include a partition, and this in turn means that [sepdist] = [sepdist$_{for}$].

The following is our official entry for the unified [sepdist] operator. It is identical to 61, the entry for [sepdist$_{for}$], except that the unsorted variables t and t' have been replaced for clarity, and the contextual relation P has been replaced by $\lambda x.\lambda y.y \in \text{Part}_i(x)$, to suggest the restriction of P to partitions. The subscript i indicates the context-dependence of Part. Formally, for any choice of i, $\text{Part}_i(x)$ denotes a subset of pairwise non-overlapping parts of x (not necessarily atomic) such that x is the mereological fusion of that subset. If x has atoms, this amounts to requiring that every atomic part of x must be part of an element of $\text{Part}_i(x)$.

(66) $[\![\text{sepdist}]\!]_{\langle\langle e,\langle vt,vt\rangle\rangle,\langle\langle et,t\rangle,\langle vt,vt\rangle\rangle\rangle}$ (official entry)
    $= \lambda H_{\langle e,\langle vt,vt\rangle\rangle}.\lambda Q_{\langle et,t\rangle}.\lambda f_{vt}.$
    $\lambda e_v.Q(\lambda y_e.\forall x\ [x \in \text{Part}_i(y) \rightarrow \exists e'[e' \leq e \wedge H(x)(f)(e')]])$

What is further needed here is a theory that predicts the resolution of the partition variable $Part_i$ dependent on context. At the minimum, it should

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[21]To avoid the figurative reading of *The committee smiled*, one can choose predicates like *have blue eyes* that make the same point but make (65) sound more nonsensical.

explain why in a sentence like (67), the partition variable must be, or at least has a strong preference for being identified with *is-atom-of*. For example, when we say *Three Dutch professors received a Nobel Prize in linguistics*, then either the partition must contain unary cells, or cells whose content is promoted to groups, like the cell containing Groenendijk and Stokhof. If there are no such groups, we cannot say it to mean that three Dutch professors are such that two of them cumulatively received a total of one prize and a third professor received another prize. While nothing so far in the theory rules out this reading, intuitively, it seems clear why the sentence would not be used that way: it would be uninformative, and the option *Three Dutch professors received two Nobel Prizes* is a viable alternative. This calls for a Gricean analysis, or in more modern terms, an analysis in terms of game theory or decision theory. I will attempt to provide such a theory in the dissertation, perhaps along the lines of Malamud (2006), who provides a decision-theoretic account of the selection of cover variables in very similar cases including two-quantifier distributivity and definite plurals.

(67) Three boys each invited four girls.   (= 22)

To summarize this section, we have identified [sepdist] as a further generalization of the distributivity operator we had obtained in Section 4, and the distributive part of the meaning of durative adverbials we have obtained in Section 3. This was done by decomposing durative prepositions into a thematic head and [sepdist], and providing independent evidence for this decomposition.

6   The syntax-semantics interface: Application to TAG

In this section, we briefly consider consequences of the present system for the syntax-semantics interface. We will see that the system is variable-free in the sense of Jacobson (1999), and arguably imposes a light load on the interface because syntax does not have to keep track of variables. As a proof of concept, a simple syntax-semantics interface to Tree-adjoining grammar (TAG; Joshi et al., 1975) is sketched. For ease of comparison, we add group-denoting noun phrases to the system, and thereby generate all eight readings of *Three boys invited four girls* listed in (Landman, 2000, ch. 6). The result is the first ever event-based semantics for TAG, which opens the door to a TAG semantic treatment of plurals, events, and quantification.

6.1   Two-quantifier sentences: Generating Landman's eight readings

In the framework presented in the previous sections, all terminals denote closed formulae (that is, they do not contain any free variables). Moreover, semantic composition is largely done by function application, with only a few cases of

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movement, mostly traceless. This is in contrast to the long list of operations in Landman's original framework (function application, type-raising, nonscopal quantifying-in, scopal quantifying-in, and a separate set of operations used to create Schein readings). This causes the present framework to impose only few requirements on a theory of the syntax-semantics interface. That is, since there are few operations, the interface does not have to determine which operation is applied. Since the framework is variable-free, to the extent that QR can be avoided, the interface does not have to manage and keep track of variables either. It is only responsible for determining the order in which lexical items combine and for managing lexical ambiguity.

The theory of (Landman, 2000, ch. 6) has for the most part already been presented in previous sections, with the exception of his treatment of collectivity. That treatment is quickly summarized: Landman assumes that in addition to their sum interpretations, noun phrases like *three boys* also have a group interpretation that maps a sum to a group atom via the $\uparrow(\cdot)$ operator (see Section 2.2). In this section, we will follow Landman in this respect and make all noun phrases ambiguous between sum and group interpretation:

(68) $\llbracket \text{three boys}_{sum} \rrbracket_{\langle et,t \rangle}$ (= 26)
     $= \lambda P_{et}.\exists X_e \, [\text{three-boys}(X) \wedge P(X)]$

(69) $\llbracket \text{three boys}_{group} \rrbracket_{\langle et,t \rangle}$
     $= \lambda P_{et}.\exists X_e \, [\text{three-boys}(X) \wedge \uparrow(P(X))]$

For greater uniformity, we will in this section depart from identifying little v with the thematic head of the external argument, and instead assume an abstract preposition [ag].

The consequence of these choices is the following. To account for the eight readings of *Three boys invited four girls* that (Landman, 2000, ch. 6) discusses, the syntax-semantics interface needs to generate the following structures (given here along with the readings in the same order as they are presented in Landman's book). These structures all involve only function application, plus the type-driven application of type-lifting functions.

(70) a. Reading 1 – scopeless reading
     A group of three boys invites a group of four girls
     $\llbracket \text{closure} \rrbracket(\llbracket \text{ag} \rrbracket(\llbracket \text{three-boys-group} \rrbracket) \, (\llbracket \text{th} \rrbracket(\llbracket \text{four-girls-group} \rrbracket)(\llbracket \text{invited} \rrbracket)))$

     b. Reading 2 – surface scope reading
     Each boy invites a group of four girls
     $\llbracket \text{closure} \rrbracket(\llbracket \text{sepdist} \rrbracket(\llbracket \text{ag} \rrbracket)(\llbracket \text{three-boys-sum} \rrbracket)$
     $(\llbracket \text{th} \rrbracket(\llbracket \text{four-girls-group} \rrbracket)(\llbracket \text{invited} \rrbracket)))$

     c. Reading 3 – inverse scope reading
     Each girl is invited by a group of three boys
     $\llbracket \text{closure} \rrbracket(\llbracket \text{sepdist} \rrbracket(\llbracket \text{th} \rrbracket)(\llbracket \text{four-girls-sum} \rrbracket)$
     $(\llbracket \text{ag} \rrbracket(\llbracket \text{three-boys-group} \rrbracket)(\llbracket \text{invited} \rrbracket)))$

     d. Reading 4 – surface scope reading

Each boy invites a sum total of four girls
⟦closure⟧(⟦sepdist⟧(⟦ag⟧)(⟦three-boys-sum⟧) (⟦th⟧(⟦four-girls-sum⟧)(⟦invited⟧)))

e. Reading 5 – inverse scope reading
Each girl is invited by a sum total of three boys
⟦closure⟧(⟦sepdist⟧(⟦th⟧)(⟦four-girls-sum⟧) (⟦ag⟧(⟦three-boys-sum⟧)(⟦invited⟧)))

f. Reading 6 – scopeless reading
A group of four girls is invited by a sum total of three boys
⟦closure⟧(⟦ag⟧(⟦three-boys-sum⟧) (⟦th⟧(⟦four-girls-group⟧)(⟦invited⟧)))

g. Reading 7 – scopeless reading
A group of three boys invites a sum total of four girls
⟦closure⟧(⟦ag⟧(⟦three-boys-group⟧) (⟦th⟧(⟦four-girls-sum⟧)(⟦invited⟧)))

h. Reading 8 – scopeless (so-called cumulative) reading
A sum total of three boys invite a sum total of four girls
⟦closure⟧(⟦ag⟧(⟦three-boys-sum⟧) (⟦th⟧(⟦four-girls-sum⟧)(⟦invited⟧)))

If we assume that NPs are lexically ambiguous between sum and group interpretations, that the [sepdist] operator optionally applies to any NP, and that NPs can be applied to the verb in any order, we will generate all and only these eight readings, up to spurious ambiguity.

To see why only these readings are generated, observe that apart from the [sepdist] operator, all lexical entries contain only existential quantifiers. Consider first those readings that do not use the [sepdist] operator. The formulae for these readings will only contain existential quantifiers, which are scopally commutative – changing their relative scope will not matter. This means that in the absence of [sepdist], it does not matter in which order the NPs are applied to the verb. Without loss of generality, let us assume that they are applied in surface order. Since either NP can either get group or sum interpretation, this leaves four possible combinations, corresponding to readings 1 and 6-8.

As for the [sepdist] operator, it will be semantically vacuous except if it applies to a sum NP that has wide scope. This is because [sepdist] asserts of the NP it combines with that it distributes over any NP that has lower scope; but only sum NPs can non-trivially distribute. We can apply [sepdist] either to the sum subject or sum object, and the other NP can either get sum or group interpretation; so this amounts to four possible combinations, corresponding to readings 2-5.

The rest of this section is devoted to a proof of concept that illustrates a concrete implementation of the syntax-semantics interface using Tree-adjoining grammar (TAG) to produce the first ever event-based semantics for TAG. In Section 6.2, we briefly describe the TAG formalism.[22] In Section 6.3, we introduce a simple, bare-bones constraint language for underspecified representations with support for scopal and lexical ambiguity. In Section 6.4, we link the two together. In Section 6.5, we describe a treatment of adjuncts.

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[22]This subsection is taken from Shen, Champollion and Joshi (2008), with minor modifications.

6.2 Tree-adjoining grammar

Tree-adjoining Grammar (TAG) was first introduced in Joshi et al. (1975). A recent review of TAG is given in Abeillé and Rambow (2001), which provides a detailed description of TAG with respect to linguistic, formal, and computational properties (see also Frank, 2002).

A TAG grammar consists of a finite set of *elementary trees* (see Fig. 9 for an example). In lexicalized TAG (LTAG), each lexical item is associated with a set of elementary trees. Each elementary tree represents a possible tree structure for the lexical item. Elementary trees carry their lexical items on their terminals. An elementary tree may have more than one lexical item.

There are two kinds of elementary trees, *initial trees* and *auxiliary trees*. A derivation always starts with an initial tree. Auxiliary trees must have exactly one *foot node*, a leaf node whose label is identical to the label of the root. The foot node is traditionally marked with an asterisk (*). Elementary trees can be combined through two operations, *substitution* and *adjunction*. Substitution is used to attach an initial tree α into a *substitution slot* of a host tree α'. Substitution slots are specially marked leaf nodes whose label must be identical with the root of α. A downarrow ($\downarrow$) symbol is used to mark substitution slots. Adjunction is used to attach an auxiliary tree α to a node n of a host tree α'. n is called the *adjunction site* of α and must carry the same label as the root and foot nodes of α. Adjunction is carried out by replacing the node n with the entire tree α. The foot node of α is then replaced by the subtree under n.

The tree resulting from the combination of elementary trees is called a *derived tree*. We can record the history of a derivation by building a *derivation tree*, in which every elementary tree used in the derivation is represented by a single node and every operation by a single arc, whose parent is the host tree of the operation. Every such arc is labeled by the Gorn address of the substitution slot or adjunction site of the host tree at which the operation has taken place. Solid arcs represent substitutions; dashed arcs indicate adjunctions.

Fig. 9 shows a sample TAG that derives the sentence *Three boys invited four girls to two parties*, along with a derived tree and a derivation tree for this sentence. The sentence we want to derive does not contain the adjunct *to two parties*; it has been added to the TAG anyway to illustrate the adjunction operation. Since we are not interested in the inner workings of noun phrases, each of them is represented as a single elementary tree. The verb is represented as a tree with substitution slots for its subject and object. There is no substitution slot for the adjunct *to two parties* since it is optional; rather, the adjunct is adjoined to the VP node. It is represented as an auxiliary tree for *to* with a substitution slot for the noun phrase *two parties*.

6.3 A simple constraint system for underspecified semantics

In this subsection, I outline a simple constraint language for underspecified semantic representations. I follow the Penn tradition of TAG semantics (Kallmeyer

and Romero, 2008) as well as much work in computational semantics, e.g. in the HPSG community (Copestake et al., 2006) in generating a scopally underspecified representation as an intermediate step. This makes it possible to map each syntactic derivation on a single semantic structure that compactly encodes scope ambiguities. The scope ambiguity constraints are inspired by hole semantics (Bos, 1995), dominance constraints (Althaus et al., 2003) and minimal recursion semantics (Fuchss et al., 2004; Copestake et al., 2006). However, this language differs from these systems in also taking semantic types into account.In addition to the scope ambiguity between the arguments of the verb, the language presented here also models the cumulative-collective ambiguity on the noun phrases and the optional presence of the [sepdist] operator.

Every lexical item is associated with one or more labeled λ expressions. With l_1, l_2 etc. ranging over labels, we will write $l_1 : expr$ to say that the expression $expr$ carries the label l_1, and we will call $expr$ the *value* of l_1. Where it doesn't lead to confusion, we will simply use the lexical items themselves as labels. For example, we will write a constraint like "th : $[\![th]\!]$" to express that the label "th" has the value $[\![th]\!]$, that is, the expression $\lambda x_e.\lambda f_{vt}.\lambda e_v.f(e) \wedge {}^*th(e) = x$ (see (39)).

We will allow several distinct λ expressions to carry the same label and we will take this to represent lexical ambiguities. More exactly, we will write $l_1 : expr_1|expr_2|...|expr_i$ to say that the expressions $expr_1, expr_2, \ldots, expr_i$ all carry the label l_1. For example, if there is a lexical item *three-boys-sum* and a lexical item *three-boys-group* and they denote different λ expressions, then we allow that each denotation is mapped to an expression that carries the label "three-boys".

A *scope constraint* $l_1 > l_2$ indicates that the λ expression labeled l_1 has to be applied to (an expression which has to be applied to...) the one labeled l_2. These applications have to be well-typed, that is, an expression E of type $\langle \alpha, \beta \rangle$ can only be applied to an expression E' if its type is α; the resulting expression is of type β. We write $l_1 > l_2 > \ldots > l_n$ to express the conjunction of constraints $l_1 > l_2 \wedge l_2 > l_3 \wedge \ldots \wedge l_{n-1} > l_n$.

A label may be *obligatory* or *optional*: A λ expression that carries an obligatory label must occur in any derivation; one that carries an optional label may or may not occur. We will write "(l_1)", with parentheses, to indicate that the label l_1 is optional. Any scope constraints that mention an optional label only need to be observed in derivations in which an expression that carries this label is present.

The underspecified representation in (71) specified in this system generates the eight readings in (70), along with spurious ambiguities as discussed above.

(71) 1. three-boys : $[\![$three-boys-sum$]\!]$ | $[\![$three-boys-group$]\!]$
     2. four-girls : $[\![$four-girls-sum$]\!]$ | $[\![$four-girls-group$]\!]$
     3. invited : $[\![$invited$]\!]$
     4. ag : $[\![$ag$]\!]$
     5. th : $[\![$th$]\!]$
     6. closure : $[\![$closure$]\!]$

7. (sepdist1) : ⟦sepdist⟧
8. (sepdist2) : ⟦sepdist⟧
9. closure > (sepdist1) > ag > three-boys > invited[23]
10. closure > (sepdist2) > th > four-girls > invited

6.4 Building the interface

We will now add semantic representations to the TAG in Fig. 9 so that it will generate the constraints in (71). See Fig. 10 for illustration. The constraints from (71) are repeated there as a help for the reader.

Most lines in (71) can be associated with elementary trees "as is", but lines 9 and 10 contain information that cannot originate in a single elementary tree becomes it mentions both the verb and the noun phrase labels. Therefore, to build these lines, it is necessary to transmit information across elementary trees. As usual in TAG semantics (Kallmeyer and Romero, 2008), we will achieve this by decorating nodes on elementary trees with feature structures that share variables with the semantic representations associated with these trees, and we will use unification to assign values to these variables. (The variables are written with boxes, as in $\boxed{sbj}$.) This will allow us to build up these lines in tandem with the syntactic derivation. A detailed feature structure system for TAG is found in Vijay-Shanker (1987). For the purpose of this example, a simplified system is enough: We decorate every substitution slots with an attribute-value matrix (AVMs), and we also put an AVM on every root node of those elementary trees that substitute into these slots. When substitution is carried out, the AVMs are unified. In this process, values are assigned to the variables in the AVMs as well as in the semantic representations associated with the trees. The simplification as compared to Vijay-Shanker (1987) and derived work is that we only use one AVM per tree node and not two.

Constraints 1 and 2 represent the meaning of noun phrases, so we associate them with the NP trees, $\alpha_{three.boys}$ and $\alpha_{four.girls}$. Constraints 3 to 8 represent the meaning of the verb, the thematic roles of its arguments, and the possibility for some of these arguments to be interpreted distributively (as modeled by the optional [sepdist] operator). We associate these constraints with the verb. Finally, constraints 9 and 10 encode the information that the [closure] operator must take highest scope, that the arguments of the verb must take scope above the verb, and that their relative scope over each other is not specified. We associate these constraints with the verb. The AVMs on the trees will cause the variables $\boxed{sbj}$ and $\boxed{obj}$ in these lines to be assigned the labels of the subject and object noun phrases.

To sum up, we now have a semantics-enriched TAG (Fig. 9) that generates the underspecified representation in (71), which in turn generates the eight readings in (70), which are given a model-theoretic interpretation by the function

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[23]We have two labels both with value ⟦sepdist⟧ because each QNP may come with its own [sepdist] operator. However, as discussed above, in this sentence at least one of the [sepdist] operators will turn out vacuous.

$[\![\cdot]\!]$ (or equivalently, mapped to λ expressions), as shown for example in Fig. **??**. More generally, this is the first treatment of events in a TAG, and the first TAG treatment of collectivity, distributivity, cumulativity, and plurals.[24]

In the next subsection, we sketch a treatment of PP adjuncts.

6.5 Modeling PP adjuncts

The only relevant difference between arguments and adjuncts for the present purpose is that adjuncts need to introduce their thematic roles and constraints on their own. We will assume that thematic roles are introduced by prepositions for PP adjuncts. Here we only model PP adjuncts; for other adjuncts, one could for example assume abstract thematic role heads whose semantics are already included in the adjuncts.

Fig. 11 shows the extension of our grammar to PP adjuncts. We also add the noun phrase *two parties*; it should be easy to see that the resulting grammar derives, among others, Schein readings of the sentence *Three boys invited four girls to two parties.* Technically, we add semantic constraints to the elementary tree β_{to} that represent the meaning and scope of the PP adjunct. These constraints are analogous to the constraints introduced by the verbal tree that represent the meaning and scope of the arguments of the verb. The constraints in β_{to} make reference to the labels corresponding to the verb and to existential closure. In the example, these are the labels "invited" and "closure". Since these labels are unknown to the tree β_{to}, they represented as variables $\boxed{v}$ and $\boxed{cl}$. An AVM on the root node provides the values of these variables as it is unified with a corresponding AVM that we add on the VP node of the verbal tree $\alpha_{invited}$.

7 Future work

This section lists areas of future research for the dissertation. Since these areas have already been pointed out throughout the text, what follows here are just loose ends – what Landman (2000) called the yellow pad problems: "A yellow pad problem is a problem for which the urgency to extend the theory to it is so high that you fill packs of yellow pads working on it, and then it doesn't make it into the book, because the book is obviously already way too long."

Here are a few of this proposal's yellow pad problems.

- This proposal has taken event semantics for granted, but as has been mentioned earlier, it is not the only game in town. The dissertation will explore to what extent the framework presented here can help shed light on the comparison between event-semantic and non-event-semantic accounts of the phenomena in consideration, and on the precise location of cumulativity. Both are currently hotly debated issues (e.g. Beck and Sauerland, 2000; Kratzer, 2007).

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[24]Except for an unpublished manuscript, Tauberer (2005).

- This proposal also contributes a fresh view on the mode of composition in event semantics, according to which quantifier raising plays a very small role. This will be compared with Landman's original account (Landman, 2000) and with the varying proposals Krifka has made over the years (Krifka, 1986, 1989, 1992, 1998). In the present framework, QR is not used to generate distributive dependencies. Unlike Landman's original system, this predicts that in languages with no covert QR, distributivity should nonetheless be possible.

- The system described in this proposal only takes into account monotone increasing quantifiers; in a setting like ours (and Landman's), maximalization operations are needed to account for other quantifiers. A promising proposal by Martin Hackl (Hackl, 2000, 2001) – see discussion in Beck and Sauerland (2000) – could be applied to improve on Landman's system.

- The literature on cover readings (e.g. Schwarzschild, 1991, 1996) bears direct relevance on any theory of quantification and plurals, but has not yet been taken into account for this proposal due to time constraints.

- The TAG presented here is a proof of concept. As such, it is extremely simple and does not model interactions with the canonical corpus of TAG semantic data discussed in the literature. Also, it does not contain durative adverbials.

- Turning to natural language processing, we would expect the present framework to be well adaptable to robust syntactic and semantic processing because, as is typical of event semantics, it is compatible with underspecified or only partially processed subcategorization frames. In the dissertation, I plan to give a proof of concept is given by adapting the framework to LTAG-spinal, a variant of TAG with desirable linguistic, computational and statistical properties which leaves the argument-adjunct distinction underspecified (Shen, Champollion and Joshi 2008).

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IP
t
$\exists e \exists X[\text{three-professors}(X)$
$\wedge \exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = X$
$\wedge {}^*\text{pat}(e) = Y] \wedge H'(e) = 1$
$\wedge [\exists e' e' \leq e] \wedge \forall e''[e'' \leq e \to \exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e'') \wedge {}^*\text{ag}(e'') = X \wedge {}^*\text{pat}(e'') = Y]]]$

[closure]
$\langle vt, t \rangle$
$\lambda f.\exists e f(e)$

vP
vt
$\lambda e.\exists X[\text{three-professors}(X)$
$\wedge \exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = X$
$\wedge {}^*\text{pat}(e) = Y] \wedge H'(e) = 1$
$\wedge [\exists e' e' \leq e] \wedge \forall e''[e'' \leq e \to \exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e'') \wedge {}^*\text{ag}(e'') = X \wedge {}^*\text{pat}(e'') = Y]]]$

three-professors
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-professors}(X)$
$\wedge P(X)]$

v'
$\langle \langle et, t \rangle, vt \rangle$
$\lambda Q.\lambda e.Q[\lambda x.[\exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = Y] \wedge H'(e) = 1$
$\wedge [\exists e' e' \leq e] \wedge \forall e''[e'' \leq e \to \exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e'') \wedge {}^*\text{ag}(e'') = x \wedge {}^*\text{pat}(e'') = Y]]]]$

[lift-v']
$\langle \langle e, vt \rangle, \langle \langle et, t \rangle, vt \rangle \rangle$
$\lambda R.\lambda Q.\lambda e.Q[\lambda x.[R(x)(e)]]$

v'
$\langle e, vt \rangle$
$\lambda x.\lambda e.[\exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = Y] \wedge H'(e) = 1$
$\wedge [\exists e' e' \leq e] \wedge \forall e''[e'' \leq e \to \exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e'') \wedge {}^*\text{ag}(e'') = x \wedge {}^*\text{pat}(e'') = Y]]]$

v'
$\langle e, vt \rangle$
$\lambda x.\lambda e.\exists Y[\text{four-prospectives}(Y)$
$\wedge {}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = Y]$

for-an-hour$_{Krifka}$
$\langle \langle e, vt \rangle, \langle e, vt \rangle \rangle$
$\lambda R.\lambda x.\lambda e.[(R(x)(e)) \wedge H'(e) = 1$
$\wedge [\exists e' e' \leq e] \wedge \forall e''[e'' \leq e \to (R(x)(e''))]]$

V^0
$\langle \langle et, t \rangle, \langle e, vt \rangle \rangle$
$\lambda Q.\lambda x.\lambda e.Q[\lambda y.[{}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = y]]$

four-prospectives
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-prospectives}(Y)$
$\wedge P(Y)]$

[lift-TV]
$\langle \langle e, \langle e, vt \rangle \rangle, \langle \langle et, t \rangle, \langle e, vt \rangle \rangle \rangle$
$\lambda V.\lambda Q.\lambda x.\lambda e.Q[\lambda y.[V(y)(x)(e)]]$

talked-to
$\langle e, \langle e, vt \rangle \rangle$
$\lambda y.\lambda x.\lambda e.[{}^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = y]$

Figure 1: Applying Krifka's entry for *for an hour* to the cumulative sentence *Three professors talked to four prospective students for an hour*.

IP
t
$\exists Y[\text{four-prospectives}(Y)$
$\wedge \exists X[\text{three-professors}(X)$
$\wedge \exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = X$
$\wedge {}^*\text{pat}(e) = Y \wedge \tau(e) = t']]]]]$

four-prospectives
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-prospectives}(Y)$
$\wedge P(Y)]$

et
$\lambda x.\exists X[\text{three-professors}(X)$
$\wedge \exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = X$
$\wedge {}^*\text{pat}(e) = x \wedge \tau(e) = t']]]]$

1

IP
t
$\exists X[\text{three-professors}(X)$
$\wedge \exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = X$
$\wedge {}^*\text{pat}(e) = g(1) \wedge \tau(e) = t']]]]$

three-professors
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-professors}(X)$
$\wedge P(X)]$

VP
et
$\lambda x.\exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = g(1) \wedge \tau(e) = t']]]$

V′
$\langle e, vt \rangle$
$\lambda x.\lambda e.[^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = g(1)]$

for-an-hour$_{Dowty/Moltmann}$
$\langle \langle e, vt \rangle, et \rangle$
$\lambda R.\lambda x.\exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[(R(x)(e)) \wedge \tau(e) = t']]]$

talked-to
$\langle e, \langle e, vt \rangle \rangle$
$\lambda y.\lambda x.\lambda e.[^*\text{talk-to}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{pat}(e) = y]$

t_1
e
$g(1)$

Figure 2: Applying Moltmann's entry for *for an hour* to the cumulative sentence *Three professors talked to four prospective students for an hour.*

IP
t
$\exists X[\text{three-professors}(X)$
$\wedge \exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[\exists Y[\text{four-prospectives}(Y)$
$\wedge\,^*\text{talk-to}(e) \wedge\,^*\text{ag}(e) = X$
$\wedge\,^*\text{pat}(e) = Y] \wedge \tau(e) = t']]]]$

three-professors
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-professors}(X)$
$\wedge P(X)]$

V$'$
et
$\lambda x.\exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[\exists Y[\text{four-prospectives}(Y)$
$\wedge\,^*\text{talk-to}(e) \wedge\,^*\text{ag}(e) = x$
$\wedge\,^*\text{pat}(e) = Y] \wedge \tau(e) = t']]]$

V$'$
$\langle e, vt \rangle$
$\lambda x.\lambda e.\exists Y[\text{four-prospectives}(Y)$
$\wedge\,^*\text{talk-to}(e) \wedge\,^*\text{ag}(e) = x$
$\wedge\,^*\text{pat}(e) = Y]$

for-an-hour$_{Dowty/Moltmann}$
$\langle\langle e, vt \rangle, et \rangle$
$\lambda R.\lambda x.\exists t[H(t) = 1 \wedge \forall t'[t'Pt \rightarrow$
$\exists e[(R(x)(e)) \wedge \tau(e) = t']]]$

V^0
$\langle\langle et, t \rangle, \langle e, vt \rangle\rangle$
$\lambda Q.\lambda x.\lambda e.Q[\lambda y.[^*\text{talk-to}(e) \wedge\,^*\text{ag}(e) = x$
$\wedge\,^*\text{pat}(e) = y]]$

four-prospectives
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-prospectives}(Y)$
$\wedge P(Y)]$

[lift-TV]
$\langle\langle e, \langle e, vt \rangle\rangle, \langle\langle et, t \rangle, \langle e, vt \rangle\rangle\rangle$
$\lambda V.\lambda Q.\lambda x.\lambda e.Q[\lambda y.[V(y)(x)(e)]]$

talked-to
$\langle e, \langle e, vt \rangle\rangle$
$\lambda y.\lambda x.\lambda e.[^*\text{talk-to}(e) \wedge\,^*\text{ag}(e) = x$
$\wedge\,^*\text{pat}(e) = y]$

Figure 3: Alternative to the previous figure.

IP
t
$\exists X[\text{three-boys}(X)$
$\wedge \forall x[x \in AT(X) \to$
$\exists e \exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{th}(e) = Y]]]$

DP
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-boys}(X)$
$\wedge \forall x[x \in AT(X)$
$\to P(x)]]$

et
$\lambda x.\exists e \exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{th}(e) = Y]$

three-boys
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-boys}(X)$
$\wedge P(X)]$

[dist]
$\langle \langle et, t \rangle, \langle et, t \rangle \rangle$
$\lambda Q.\lambda P.Q(\lambda y.\forall x[x \in AT(y)$
$\to P(x)])$

1

IP
t
$\exists e \exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = g(1)$
$\wedge {}^*\text{th}(e) = Y]$

[closure]
$\langle vt, t \rangle$
$\lambda f.\exists e f(e)$

vP
vt
$\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = g(1)$
$\wedge {}^*\text{th}(e) = Y]$

t_1
e
$g(1)$

v'
$\langle e, vt \rangle$
$\lambda x.\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{th}(e) = Y]$

V^0
$\langle \langle et, t \rangle, \langle e, vt \rangle \rangle$
$\lambda Q.\lambda x.\lambda e.Q[\lambda y.[{}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{th}(e) = y]]$

four-girls
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-girls}(Y)$
$\wedge P(Y)]$

[lift-TV]
$\langle \langle e, \langle e, vt \rangle \rangle, \langle \langle et, t \rangle, \langle e, vt \rangle \rangle \rangle$
$\lambda V.\lambda Q.\lambda x.\lambda e.Q[\lambda y.[V(y)(x)(e)]]$

invited
$\langle e, \langle e, vt \rangle \rangle$
$\lambda y.\lambda x.\lambda e.[{}^*\text{invite}(e) \wedge {}^*\text{ag}(e) = x$
$\wedge {}^*\text{th}(e) = y]$

Figure 4: An example of the [dist] operator in the sentence *Three boys invited four girls.*

IP
t
$\exists e\exists X[\text{three-boys}(X)$
$\wedge\,^*\text{ag}(e) = X \wedge \exists Y[\text{four-girls}(Y)$
$\wedge\,^*\text{invite}(e) \wedge\,^*\text{th}(e) = Y]]$

[closure]
$\langle vt, t\rangle$
$\lambda f.\exists e f(e)$

vP
vt
$\lambda e.\exists X[\text{three-boys}(X)$
$\wedge\,^*\text{ag}(e) = X \wedge \exists Y[\text{four-girls}(Y)$
$\wedge\,^*\text{invite}(e) \wedge\,^*\text{th}(e) = Y]]$

three-boys
$\langle et, t\rangle$
$\lambda P.\exists X[\text{three-boys}(X)$
$\wedge P(X)]$

v'
$\langle\langle et, t\rangle, vt\rangle$
$\lambda Q.\lambda e.Q[\lambda x.[^*\text{ag}(e) = x$
$\wedge\exists Y[\text{four-girls}(Y)$
$\wedge\,^*\text{invite}(e) \wedge\,^*\text{th}(e) = Y]]]$

[lift-v']
$\langle\langle e, vt\rangle, \langle\langle et, t\rangle, vt\rangle\rangle$
$\lambda R.\lambda Q.\lambda e.Q[\lambda x.[R(x)(e)]]$

v'
$\langle e, vt\rangle$
$\lambda x.\lambda e.[^*\text{ag}(e) = x$
$\wedge\exists Y[\text{four-girls}(Y)$
$\wedge\,^*\text{invite}(e) \wedge\,^*\text{th}(e) = Y]]$

[v]
$\langle vt, \langle e, vt\rangle\rangle$
$\lambda f.\lambda x.\lambda e.[^*\text{ag}(e) = x$
$\wedge f(e)]$

VP
vt
$\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge\,^*\text{invite}(e) \wedge\,^*\text{th}(e) = Y]$

invited
vt
$\lambda e.^*\text{invite}(e)$

DP
$\langle vt, vt\rangle$
$\lambda f.\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge f(e) \wedge\,^*\text{th}(e) = Y]$

θ^0
$\langle\langle et, t\rangle, \langle vt, vt\rangle\rangle$
$\lambda Q.\lambda f.\lambda e.Q[\lambda x.[f(e) \wedge\,^*\text{th}(e) = x]]$

four-girls
$\langle et, t\rangle$
$\lambda P.\exists Y[\text{four-girls}(Y)$
$\wedge P(Y)]$

[lift]
$\langle\langle e, \langle vt, vt\rangle\rangle, \langle\langle et, t\rangle, \langle vt, vt\rangle\rangle\rangle$
$\lambda H.\lambda Q.\lambda f.\lambda e.Q[\lambda x.[H(x)(f)(e)]]$

[theme]
$\langle e, \langle vt, vt\rangle\rangle$
$\lambda x.\lambda f.\lambda e.[f(e) \wedge\,^*\text{th}(e) = x]$

Figure 5: A sample derivation using essential separation. The sentence is *Three boys invited four girls.*

IP
t
$\exists e \exists X[\text{three-boys}(X)$
$\wedge\,^{*}\text{ag}(e) = X$
$\wedge \exists Y[\text{four-girls}(Y)$
$\wedge \forall x[x \in AT(Y) \rightarrow \exists e'[e' \leq e \wedge \exists Z[\text{two-flowers}(Z)$
$\wedge\,^{*}\text{give}(e') \wedge\,^{*}\text{th}(e') = Z] \wedge\,^{*}\text{ben}(e') = x]]]]$

[closure]
$\langle vt, t \rangle$
$\lambda f.\exists e f(e)$

vP
vt
$\lambda e.\exists X[\text{three-boys}(X)$
$\wedge\,^{*}\text{ag}(e) = X$
$\wedge \exists Y[\text{four-girls}(Y)$
$\wedge \forall x[x \in AT(Y) \rightarrow \exists e'[e' \leq e \wedge \exists Z[\text{two-flowers}(Z)$
$\wedge\,^{*}\text{give}(e') \wedge\,^{*}\text{th}(e') = Z] \wedge\,^{*}\text{ben}(e') = x]]]]$

three-boys
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-boys}(X)$
$\wedge P(X)]$

v'
$\langle \langle et, t \rangle, vt \rangle$
$\lambda Q.\lambda e.Q[\lambda x.[^{*}\text{ag}(e) = x$
$\wedge \exists Y[\text{four-girls}(Y)$
$\wedge \forall x[x \in AT(Y) \rightarrow \exists e'[e' \leq e \wedge \exists Z[\text{two-flowers}(Z)$
$\wedge\,^{*}\text{give}(e') \wedge\,^{*}\text{th}(e') = Z] \wedge\,^{*}\text{ben}(e') = x]]]]]$

[lift-v']
$\langle \langle e, vt \rangle, \langle \langle et, t \rangle, vt \rangle \rangle$
$\lambda R.\lambda Q.\lambda e.Q[\lambda x.[R(x)(e)]]$

v'
$\langle e, vt \rangle$
$\lambda x.\lambda e.[^{*}\text{ag}(e) = x$
$\wedge \exists Y[\text{four-girls}(Y)$
$\wedge \forall x[x \in AT(Y) \rightarrow \exists e'[e' \leq e \wedge \exists Z[\text{two-flowers}(Z)$
$\wedge\,^{*}\text{give}(e') \wedge\,^{*}\text{th}(e') = Z] \wedge\,^{*}\text{ben}(e') = x]]]]$

[v]
$\langle vt, \langle e, vt \rangle \rangle$
$\lambda f.\lambda x.\lambda e.[^{*}\text{ag}(e) = x$
$\wedge f(e)]$

VP
vt
$\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge \forall x[x \in AT(Y) \rightarrow \exists e'[e' \leq e \wedge \exists Z[\text{two-flowers}(Z)$
$\wedge\,^{*}\text{give}(e') \wedge\,^{*}\text{th}(e') = Z] \wedge\,^{*}\text{ben}(e') = x]]]$

DP
$\langle vt, vt \rangle$
$\lambda f.\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge \forall x[x \in AT(Y) \rightarrow \exists e'[e' \leq e \wedge f(e') \wedge\,^{*}\text{ben}(e') = x]]]$

VP
vt
$\lambda e.\exists Z[\text{two-flowers}(Z)$
$\wedge\,^{*}\text{give}(e) \wedge\,^{*}\text{th}(e) = Z]$

θ^{0}
$\langle \langle et, t \rangle, \langle vt, vt \rangle \rangle$
$\lambda Q.\lambda f.\lambda e.Q(\lambda y.\forall x[x \in AT(y) \rightarrow$
$\exists e'[e' \leq e \wedge f(e') \wedge\,^{*}\text{ben}(e') = x]])$

four-girls
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-girls}(Y)$
$\wedge P(Y)]$

gave
vt
$\lambda e.^{*}\text{give}(e)$

DP
$\langle vt, vt \rangle$
$\lambda f.\lambda e.\exists Z[\text{two-flowers}(Z)$
$\wedge f(e) \wedge\,^{*}\text{th}(e) = Z]$

[sepdist$_{QNP}$]
$\langle \langle e, \langle vt, vt \rangle \rangle, \langle \langle et, t \rangle, \langle vt, vt \rangle \rangle \rangle$
$\lambda H.\lambda Q.\lambda f.\lambda e.Q(\lambda y.\forall x[x \in AT(y) \rightarrow$
$\exists e'[e' \leq e \wedge (H(x)(f)(e'))]])$

[ben]
$\langle e, \langle vt, vt \rangle \rangle$
$\lambda x.\lambda f.\lambda e.[f(e) \wedge\,^{*}\text{ben}(e) = x]$

θ^{0}
$\langle \langle et, t \rangle, \langle vt, vt \rangle \rangle$
$\lambda Q.\lambda f.\lambda e.Q[\lambda x.[f(e) \wedge\,^{*}\text{th}(e) = x]]$

two-flowers
$\langle et, t \rangle$
$\lambda P.\exists Z[\text{two-flowers}(Z)$
$\wedge P(Z)]$

[lift]
$\langle \langle e, \langle vt, vt \rangle \rangle, \langle \langle et, t \rangle, \langle vt, vt \rangle \rangle \rangle$
$\lambda H.\lambda Q.\lambda f.\lambda e.Q[\lambda x.[H(x)(f)(e)]]$

[theme]
$\langle e, \langle vt, vt \rangle \rangle$
$\lambda x.\lambda f.\lambda e.[f(e) \wedge\,^{*}\text{th}(e) = x]$

Figure 6: A sample derivation using the [sepdist$_{QNP}$] operator. The sentence is *Three boys gave four girls two flowers.*

IP
t
$\exists e \exists X[\text{three-boys}(X)$
$\wedge \forall x[x \in AT(X) \to \exists e'[e' \leq e \wedge {}^*\text{ag}(e') = x$
$\wedge \exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e') \wedge {}^*\text{th}(e') = Y]]]]$

[closure]
$\langle vt, t \rangle$
$\lambda f.\exists e f(e)$

vP
vt
$\lambda e.\exists X[\text{three-boys}(X)$
$\wedge \forall x[x \in AT(X) \to$
$\exists e'[e' \leq e \wedge {}^*\text{ag}(e') = x \wedge \exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e') \wedge {}^*\text{th}(e') = Y]]]]$

three-boys
$\langle et, t \rangle$
$\lambda P.\exists X[\text{three-boys}(X)$
$\wedge P(X)]$

v'
$\langle \langle et, t \rangle, vt \rangle$
$\lambda Q.\lambda e.Q(\lambda y.\forall x[x \in AT(y) \to$
$\exists e'[e' \leq e \wedge {}^*\text{ag}(e') = x$
$\wedge \exists Y[\text{four-girls}(Y) \wedge {}^*\text{invite}(e') \wedge {}^*\text{th}(e') = Y]]])$

[sepdist$'_{QNP}$]
$\langle \langle e, vt \rangle, \langle \langle et, t \rangle, vt \rangle \rangle$
$\lambda R.\lambda Q.\lambda e.Q(\lambda y.\forall x[x \in AT(y) \to$
$\exists e'[e' \leq e \wedge (R(x)(e'))]])$

v'
$\langle e, vt \rangle$
$\lambda x.\lambda e.[{}^*\text{ag}(e) = x$
$\wedge \exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{th}(e) = Y]]$

$[v]$
$\langle vt, \langle e, vt \rangle \rangle$
$\lambda f.\lambda x.\lambda e.$
$[{}^*\text{ag}(e) = x$
$\wedge f(e)]$

VP
vt
$\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge {}^*\text{invite}(e) \wedge {}^*\text{th}(e) = Y]$

invited
vt
$\lambda e.{}^*\text{invite}(e)$

DP
$\langle vt, vt \rangle$
$\lambda f.\lambda e.\exists Y[\text{four-girls}(Y)$
$\wedge f(e) \wedge {}^*\text{th}(e) = Y]$

θ^0
$\langle \langle et, t \rangle, \langle vt, vt \rangle \rangle$
$\lambda Q.\lambda f.\lambda e.Q[\lambda x.[f(e) \wedge {}^*\text{th}(e) = x]]$

four-girls
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-girls}(Y)$
$\wedge P(Y)]$

[lift]
$\langle \langle e, \langle vt, vt \rangle \rangle, \langle \langle et, t \rangle, \langle vt, vt \rangle \rangle \rangle$
$\lambda H.\lambda Q.\lambda f.\lambda e.Q[\lambda x.[H(x)(f)(e)]]$

[theme]
$\langle e, \langle vt, vt \rangle \rangle$
$\lambda x.\lambda f.\lambda e.[f(e) \wedge {}^*\text{th}(e) = x]$

Figure 7: Using [sepdist$'_{QNP}$] instead of [dist]. The sentence is *Three boys invited four girls.*

IP
t
$\exists e \exists Y[\text{four-girls}(Y) \wedge \forall x[x \in AT(Y) \rightarrow$
$\exists e'[e' \leq e \wedge \exists X[\text{three-boys}(X)$
$\wedge\, ^*\text{ag}(e') = X \wedge\, ^*\text{invite}(e')] \wedge\, ^*\text{th}(e') = x]]]$

[closure]
$\langle vt, t \rangle$
$\lambda f.\exists e f(e)$

vP
vt
$\lambda e.\exists Y[\text{four-girls}(Y) \wedge \forall x[x \in AT(Y) \rightarrow$
$\exists e'[e' \leq e \wedge \exists X[\text{three-boys}(X)$
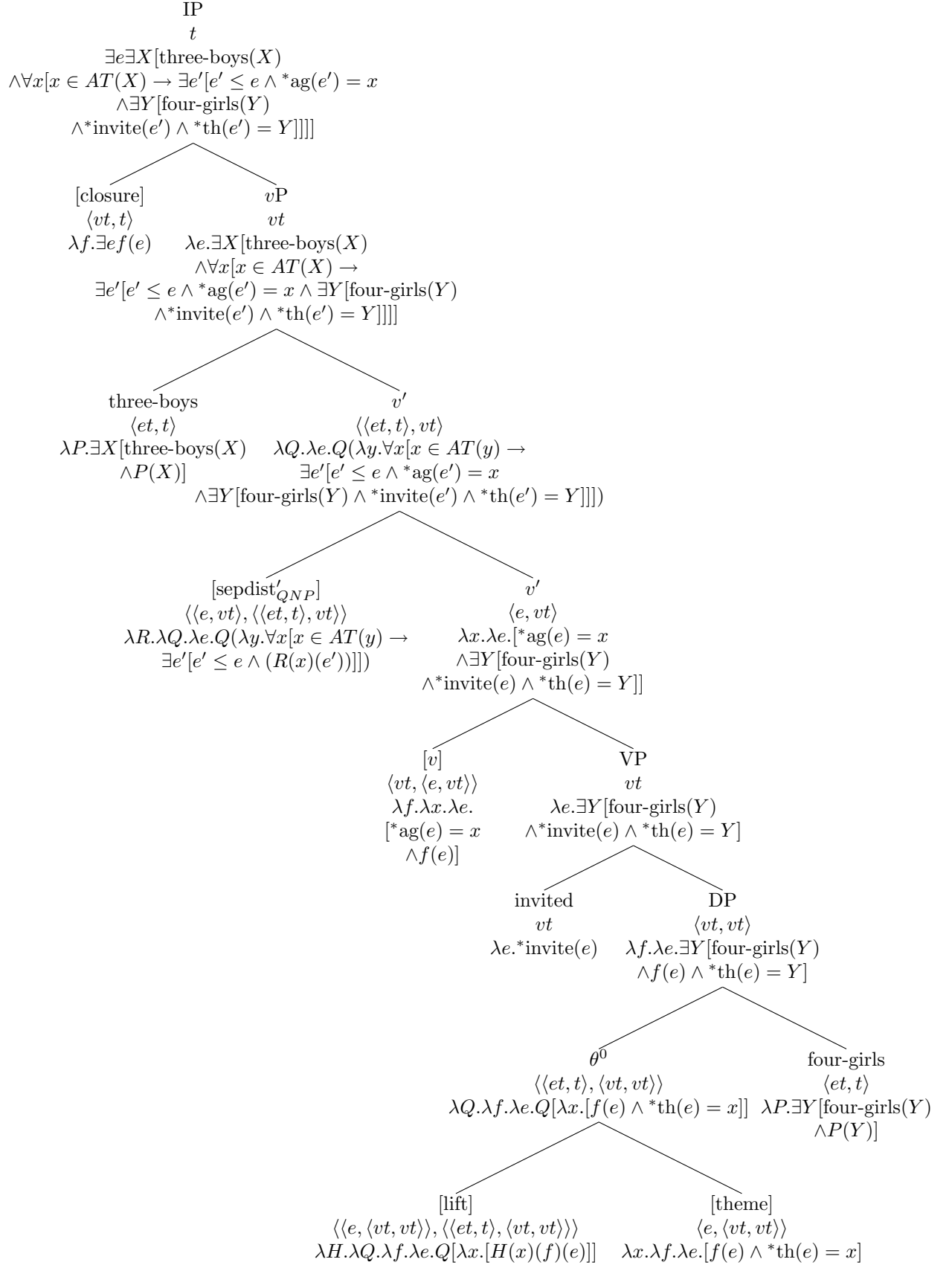$\wedge\, ^*\text{ag}(e') = X \wedge\, ^*\text{invite}(e')] \wedge\, ^*\text{th}(e') = x]]]$

DP
$\langle vt, vt \rangle$
$\lambda f.\lambda e.\exists Y[\text{four-girls}(Y) \wedge \forall x[x \in AT(Y) \rightarrow$
$\exists e'[e' \leq e \wedge f(e') \wedge\, ^*\text{th}(e') = x]]]$

vP
vt
$\lambda e.\exists X[\text{three-boys}(X)$
$\wedge\, ^*\text{ag}(e) = X \wedge\, ^*\text{invite}(e)]$

θ^0
$\langle \langle et, t \rangle, \langle vt, vt \rangle \rangle$
$\lambda Q.\lambda f.\lambda e.$
$Q(\lambda y.\forall x[x \in AT(y) \rightarrow$
$\exists e'[e' \leq e \wedge f(e') \wedge\, ^*\text{th}(e') = x]])$

four-girls
$\langle et, t \rangle$
$\lambda P.\exists Y[\text{four-girls}(Y)$
$\wedge P(Y)]$

three-boys
$\langle et, t \rangle$
$\lambda P.\exists X$
$[\text{three-boys}(X)$
$\wedge P(X)]$

v'
$\langle \langle et, t \rangle, vt \rangle$
$\lambda Q.\lambda e.Q[\lambda x.$
$[^*\text{ag}(e) = x \wedge\, ^*\text{invite}(e)]]$

[sepdist$_{QNP}$]
$\langle \langle e, \langle vt, vt \rangle \rangle, \langle \langle et, t \rangle, \langle vt, vt \rangle \rangle \rangle$
$\lambda H.\lambda Q.\lambda f.\lambda e.$
$Q(\lambda y.\forall x[x \in AT(y) \rightarrow$
$\exists e'[e' \leq e \wedge (H(x)(f)(e'))]])$

[theme]
$\langle e, \langle vt, vt \rangle \rangle$
$\lambda x.\lambda f.\lambda e.$
$[f(e) \wedge\, ^*\text{th}(e) = x]$

[lift-v']
$\langle \langle e, vt \rangle, \langle \langle et, t \rangle, vt \rangle \rangle$
$\lambda R.\lambda Q.\lambda e.$
$Q[\lambda x.[R(x)(e)]]$

v'
$\langle e, vt \rangle$
$\lambda x.\lambda e.[^*\text{ag}(e) = x$
$\wedge\, ^*\text{invite}(e)]$

[v]
$\langle vt, \langle e, vt \rangle \rangle$
$\lambda f.\lambda x.\lambda e.$
$[^*\text{ag}(e) = x \wedge f(e)]$
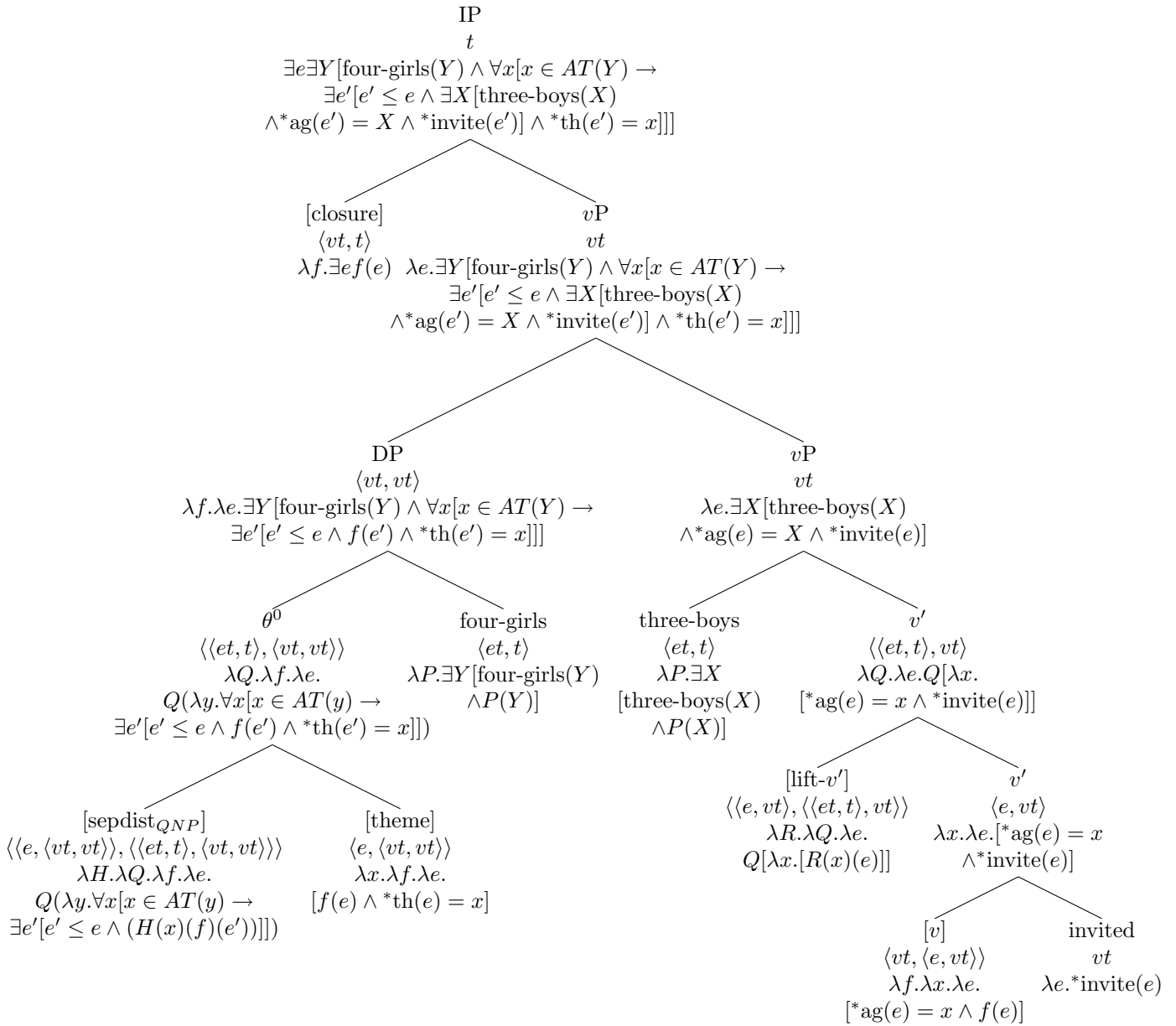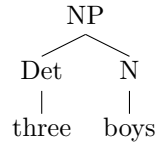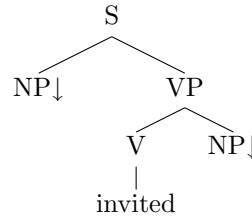
invited
vt
$\lambda e.^*\text{invite}(e)$

Figure 8: An example of inverse distributive scope. Note that the object quantifier has raised without leaving a trace behind. The sentence is *Three boys invited four girls.*
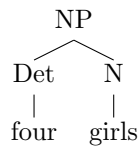
Elementary trees
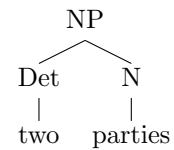
Derived tree
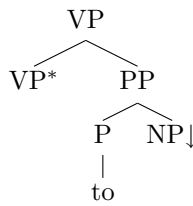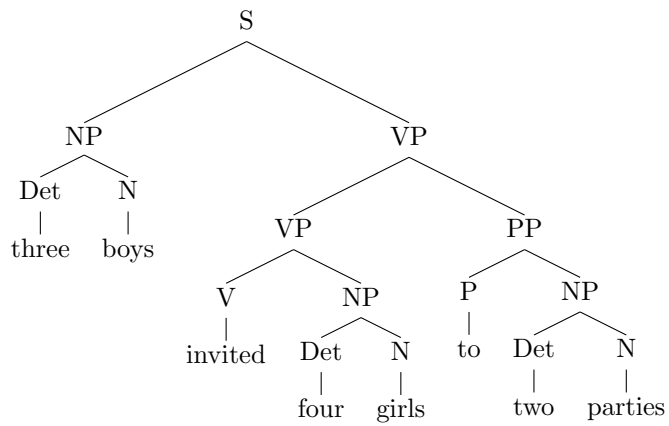

Derivation tree
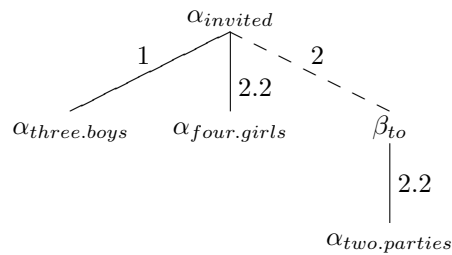
Figure 9: A TAG that derives the sentence *Three boys invited four girls to two parties.*

Entry	Syntax	Semantics
$\alpha_{three.boys}$	NP[ARG three-boys] Det — N | | three boys	three-boys : $[\![$three-boys$_{sum}]\!]$ $\mid$ $[\![$three-boys$_{group}]\!]$
$\alpha_{invited}$	S NP↓[ARG $\boxed{sbj}$] VP V NP↓[ARG $\boxed{obj}$] | invited	invited : $[\![$invited$]\!]$ ag : $[\![$ag$]\!]$ th : $[\![$th$]\!]$ closure : $[\![$closure$]\!]$ (sepdist1) : $[\![$sepdist$]\!]$ (sepdist2) : $[\![$sepdist$]\!]$ closure > (sepdist1) > ag > $\boxed{sbj}$ > invited closure > (sepdist2) > th > $\boxed{obj}$ > invited
$\alpha_{four.girls}$	NP[ARG four-girls] Det — N | | four girls	four-girls : $[\![$four-girls$_{sum}]\!]$ $\mid$ $[\![$four-girls$_{group}]\!]$

S
NP[ARG three-boys]   VP
Det   N   V   NP[ARG four-girls]
\| \| \| Det   N
three boys invited \| \|
                   four girls

1. three-boys :
   $[\![$three-boys$_{sum}]\!]$ $\mid$ $[\![$three-boys$_{group}]\!]$
2. four-girls :
   $[\![$four-girls$_{sum}]\!]$ $\mid$ $[\![$four-girls$_{group}]\!]$
3. invited : $[\![$invited$]\!]$
4. ag : $[\![$ag$]\!]$
5. th : $[\![$th$]\!]$
6. closure : $[\![$closure$]\!]$
7. (sepdist1) : $[\![$sepdist$]\!]$
8. (sepdist2) : $[\![$sepdist$]\!]$
9. closure > (sepdist1) > ag
   > three-boys > invited
10. closure > (sepdist2) > th
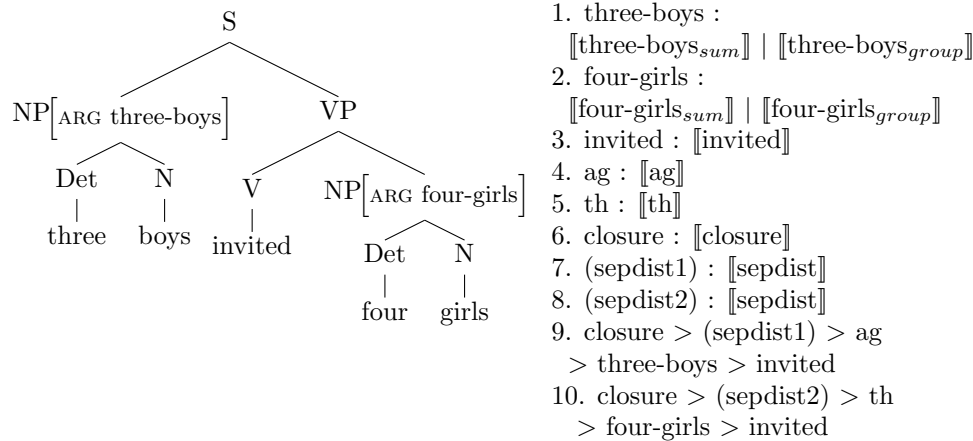   > four-girls > invited

Figure 10: On top, the same TAG as in Fig. 9 (except for the PP *to two parties*), augmented with a semantic representation. Below, a derived tree for *Three boys invited four girls*, along with the underspecified semantic representation generated by the entries above.

Entry	Syntax	Semantics
β_{to}	$\text{VP}\begin{bmatrix}\text{CL} & \boxed{cl}\\ \text{V} & \boxed{v}\end{bmatrix}$ — VP* — PP — P — to — NP↓ $\begin{bmatrix}\text{ARG} & \boxed{np}\end{bmatrix}$	loc : $[\![\text{loc}]\!]$ (sepdist3) : $[\![\text{sepdist}]\!]$ $\boxed{cl}$ > (sepdist3) > loc > $\boxed{np}$ > $\boxed{v}$
$\alpha_{two.parties}$	$\text{NP}\begin{bmatrix}\text{ARG two-parties}\end{bmatrix}$ — Det — N — two — parties	two-parties : $[\![\text{two-parties}_{sum}]\!]$ $\mid [\![\text{two-parties}_{group}]\!]$
$\alpha_{invited}$ (revised)	S — NP↓ $\begin{bmatrix}\text{ARG} & \boxed{sbj}\end{bmatrix}$ VP$\begin{bmatrix}\text{CL} & \text{closure}\\ \text{V} & \text{invited}\end{bmatrix}$ — V — invited — NP↓ $\begin{bmatrix}\text{ARG} & \boxed{obj}\end{bmatrix}$	*as in Fig. 10*

Figure 11: An extension of the TAG in Fig. 10 for the PP *to two parties*.