Plurality and temporal modification*

To appear in *Linguistics and Philosophy*

Ron Artstein
artstein [at] essex.ac.uk

Nissim Francez
francez [at] cs.technion.ac.il

January 13, 2006

Abstract A semantics with plural entities and plural times accounts for cumulative relations between plural arguments and temporal expressions. The semantics equips nominal, verbal and sentential meanings with temporal context variables and treats temporal modifiers as temporal generalized quantifiers; cumulative conjunction, however, takes place at types lower than generalized quantifiers. The mediation of temporal context variables allows cumulative relations to percolate between an argument in a main clause and one in a temporal clause, in apparent violation of locality restrictions. Plural times form a semilattice structure imposed on the set of intervals; no interaction is observed between this and the internal temporal structure of intervals.

1 Introduction

Plural arguments (subject or object) may exhibit cumulative relations with temporal and locative expressions: sentence (1) may be true even if each conference only ended once, and sentence (2) may be true if Bob only buried each witness in one place.

(1) The conferences ended on Tuesday, Wednesday and Thursday.

(2) Bob buried the witnesses in basements and garbage dumps.

To account for such data we present a minimal extension of the theory of quantificational temporal and locative modifiers (Pratt and Francez 1997, 2001; von Stechow 2002; Francez and Steedman to appear; Artstein 2005). The above works assume that the temporal domain is a set of intervals (Francez and Steedman add a locative domain), and analyze all temporal modifiers as generalized quantifiers (von Stechow 2002 uses Quantifier Raising in Logical Form). Our extension makes the following amendments.

1. The temporal and locative domains have a structure which represents plural times and locations (cf. Krifka 1990b; Landman 1996, 2000 for similar claims about events).

2. Temporal and locative modifiers may be of a lower type than generalized quantifiers.

*This is an extended version of a paper presented at the Fourteenth Amsterdam Colloquium (Artstein and Francez 2003).

An additional observation, namely that cumulative relations are allowed *across* temporal and locative clause boundaries, follows from our analysis without violating the generalization of Beck and Sauerland (2000) that cumulative relations are subject to locality constraints.

Cumulative readings, also called codistributive readings, obtain between plural arguments, as in the following examples.

(3) George and John kissed the babies.

(4) The babies were born to Jeanne and Jill.

Sentence (3) may be true if each of George and John kissed all of the babies, but it is also true if each of them only kissed some of the babies. Likewise, sentence (4) does not imply that each baby was born to two mothers (which would be inconsistent with the world as we know it); it is true if some of the babies were born to Jeanne and the others were born to Jill. In general, a cumulative relation holds between two plural arguments when each element in the extension of the first argument (the babies in example (4)) stands in the corresponding singular relation ("be born to") to at least one element in the extension of the second argument (Jeanne and Jill), and vice versa. Such a reading stands in contrast to distributive readings, as in the babies smiled, which implies that each of the babies smiled, and also to collective readings as in the babies met, which is not reducible to properties of individual babies. Cumulative readings of nominal arguments have been discussed extensively in the literature (see e.g. Scha 1981; Link 1983; Krifka 1990a; Schwarzschild 1994; Landman 1996, 2000; Sternefeld 1998; Winter 2000).

Cumulative relations are also possible between a nominal argument (subject or object) and a temporal or locative expression, as in (1) and (2) above. It is the plural argument in the above sentences which allows for a reading that is consistent with one ending per conference and one burial per witness. If we replace the plural arguments with universally quantified ones, we get sentences which entail that each conference ended more than once, and each witness was buried more than once.

(5) Each conference ended on Tuesday, Wednesday and Thursday.

(6) Bob buried each witness in basements and garbage dumps.

Another point to note is that the plural temporal and locative expressions in (1) and (2) denote plural times and locations rather than a long time interval or a broad location. Sentence (7) is consistent with all the conferences ending on one day, whereas sentence (1) is not; likewise, sentence (8) is consistent with burying all the witnesses in one place, while sentence (2) is not.

(7) The conferences ended between Tuesday and Thursday.

(8) Bob buried the witnesses between basements and garbage dumps.

This paper develops a semantics in which plural temporal expressions denote plural temporal objects (locations are omitted for brevity). We will not get into the the exact lexical meaning of between, but a natural interpretation is that it involves a function that maps plural time intervals to single intervals, e.g. the plural interval denoted by Tuesday and Thursday is mapped to a single interval than spans both members of the plurality.

The semantics of temporal and locative modification equips nominal, verbal and sentential meanings with contextual variables that range over times and locations (Pratt and Francez 1997, 2001; von Stechow 2002; Francez and Steedman to appear; Artstein 2005). Originally, these variables were introduced to capture the correct cascading, or nesting, of PP modifiers. We propose that these variables range over plural entities as well. Cumulative readings are captured through the star operator of Link (1983), and the cumulative relations between nominal and temporal or locative arguments are mediated through the context variables. A benefit of the context variable approach is that it gives a straightforward account of cumulative relations between nominal arguments that are separated by a clause boundary. Sauerland (1998), Beck (2000), and Beck and Sauerland (2000) observe that cumulative readings are generally subject to a locality restriction, stating roughly that the two plural arguments should be in the same clause, or arguments of the same predicate. But this restriction does not prevent a cumulative relation between an argument in a temporal or locative adjunct clause and an argument outside that clause. Thus, sentence (10) has a (true) cumulative reading, just like (9) does; likewise, sentence (11) has a cumulative reading.

(9) Andrew Johnson and Lyndon B. Johnson succeeded Lincoln and Kennedy.

(10) Andrew Johnson and Lyndon B. Johnson took office after Lincoln and Kennedy were assassinated.

(11) A cherry tree and an apple tree grow where Lincoln and Kennedy were shot.

According to the theory developed in this paper, cumulative readings are available in the above examples because temporal and locative modification relates the context variables of the main and adjunct clauses. A cumulative relation does not obtain directly between an argument in the main clause and one in the embedded clause; rather, a cumulative relation holds within each clause between the nominal argument and the temporal or locative context variable, and the relation between arguments in the two clauses follows from the relations between the context variables.

Section 2 presents the underlying theories of plural representation and temporal modification. Section 3 introduces temporal generalized quantifiers and derives sentences with cumulative readings. Sections 4, 5, and 6 extend the analysis to temporal cascades, coordinate temporal PPs, and coordinate temporal prepositions. Section 7 analyzes cumulative readings of sentences with embedded temporal clauses, and section 8 offers a summary and conclusion.

2 Plural times

We assume a plural ontology similar to that of Link (1983), where individuals and pluralities are of the same type. The domain is sorted into two types – e for entities and i for time intervals; each subdomain constitutes a semilattice which is isomorphic to a structure where pluralities are freely formed sets of individuals (cf. Landman 1989). Atoms of type e are individual entities. Atoms of type i are intervals: given a time axis $\langle A, \leq \rangle$ which is a set of instants A ordered by a precedence relation $\leq$ (a total ordering), we define a *basic interval* as any convex subset of A (the convexity property is due to convention; nothing in what follows hinges upon it). These basic intervals form the atoms of the semilattice I of plural time intervals.

Plural time intervals are of the same logical type as basic time intervals (type i), but they have a mereological structure. Thus, distinct plural time intervals can occupy overlapping and even identical parts of the time axis. For example, suppose John ate from 15:00 to 16:00 and slept from 16:00 to 18:00, while Mary slept from 15:00 to 17:00 and ate from 17:00 to 18:00. The plural time interval corresponding to John's eating and sleeping is the join of two basic intervals, namely $[15, 16] \oplus [16, 18]$, while the plural time interval corresponding to Mary's sleeping and eating is the join of different intervals, namely $[15, 17] \oplus [17, 18]$. These two plural intervals project to the same part of the time axis, but are distinct in that they have different structures.

The relation between the semilattice of intervals I and the set of instants A is similar to the relation noted by Link (1983) between count individuals and the matter that they consist of – for example, the cards and the deck of cards refer to distinct individuals constituted of the same substance matter (Link 1983, page 304). The two structures of the temporal domain serve distinct purposes: the time axis determines precedence relations among (basic) intervals, while the semilattice structure accounts for plurality.

We impose no restrictions on $\langle A, \leq \rangle$ other than the requirement that $\leq$ should be a total ordering. In particular, we are agnostic as to whether $\langle A, \leq \rangle$ is discrete or dense. This is not meant to imply that such restrictions are not needed; they just appear to be of little or no consequence to the issues of plurality treated here. The same goes for the precedence relation on (basic) intervals: there are various questions as to the proper way of determining this relation from the ordering of instants (regarding overlapping intervals in particular), but we have not found an interesting interaction of these issues with matters of plurality.

The formalism used in this paper is similar in notation to that of Artstein (2005), but temporal context variables are bound in all formulas as in Pratt and Francez (2001) and Francez and Steedman (to appear). The reader is referred to the above works for a full introduction to temporal generalized quantifier theory; here we will only give the essentials. We use a two-sorted language with lambda abstraction, which represents times explicitly. Temporal predicates are assumed to have a temporal argument of type i corresponding to the event time; for conciseness and clarity we will only show the temporal argument of event predicates, writing for example $\lambda i.\mathbf{meeting}(i)$ instead of the more cumbersome $\lambda i.\exists e[i = \text{time}(e) \wedge \mathbf{meeting}(e)]$. Representations are enriched by temporal context variables, which are variables of type i that stand for time frames for the evaluation of sentences (Pratt and Francez 1997, 2001). Propositions are not simply truth values, but functions of type it from temporal contexts to truth values; the highest temporal context variable stands for the overall temporal context of evaluation, and is indicated by a distinguished variable $\hat{\imath}$. Temporal prepositions are functions from temporal contexts and intervals to temporal intervals, so $\mathbf{after}(i, j)$ denotes the interval spanning from the end of the interval j to end of its context i (assuming that $j \subseteq i$, see (51) below). Temporal modification involves subordinating the temporal context of the modified expression to that of the temporal modifier, as in the following derivation. We ignore tense throughout this paper.

(12) Modified expression – Bill cried: $\lambda\hat{\imath}.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{cry}(\mathbf{bill})(i)]$

(13) Modifier – after each meeting:
$\lambda J \lambda\hat{\imath}.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow J(\mathbf{after}(\hat{\imath}, i))]$

(14) Bill cried after each meeting:
$\lambda\hat{\imath}.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow \exists i'[i' \subseteq \mathbf{after}(\hat{\imath}, i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]$

We use a **boldface** font for constants in the logical language, and a sans-serif font for natural language expressions.

The following additions to the logical language are used in the translations of plural expressions. The symbol '$\oplus$' denotes the join operations on the semilattice structures of entities and time intervals (Link 1983), and the symbol '$\sqsubseteq$' denotes the inherent order on these semilattices (the part-of relation, Link's Π).

(15) $[\![x \oplus y]\!]$ is the join of $[\![x]\!]$ and $[\![y]\!]$ (a plural individual).
$[\![i \oplus j]\!]$ is the join of $[\![i]\!]$ and $[\![j]\!]$ (a plural time interval).

(16) $[\![x \sqsubseteq y]\!] = 1$ if $[\![x]\!]$ is part of $[\![y]\!]$ in the semilattice of individuals.
$[\![i \sqsubseteq j]\!] = 1$ if $[\![i]\!]$ is part of $[\![j]\!]$ in the semilattice of intervals.

The star operator (Link 1983) translates plural expressions. If $\mathcal{P}$ is a one-place predicate, then the plural predicate $*\mathcal{P}$ is true of an argument just in case the argument is composed of one or more parts of which $\mathcal{P}$ holds.

(17) For any $\mathcal{P}$ of type σt and a of type σ, σ an individual type (e or i):

$[\![*\mathcal{P}(a)]\!] = 1$ iff $[\![a]\!]$ is the join of n objects $[\![a_1]\!], \ldots, [\![a_n]\!]$ ($n \geq 1$), and for each $i \leq n$, $[\![\mathcal{P}(a_i)]\!] = 1$.

For example, the sentence Bill and Mary cried would be translated (without temporal information) as $*$**cry**(**bill** $\oplus$ **mary**), entailing that each of Bill and Mary cried.

Two-place plural predicates allow for cumulative relations between their arguments (Scha 1981; Krifka 1990a,b): each binary relation $\mathcal{R}$ corresponds to a plural relation $*\mathcal{R}$ which licenses a cumulative reading (the question of where cumulativity originates is orthogonal to the matter at hand, so we will not go into the debate on whether it arises through lexical or syntactic means; for recent discussion see Winter 2000; Beck 2000; Beck and Sauerland 2000).

(18) For any $\mathcal{R}$ of type $\sigma\tau t$, a of type σ and b of type τ, σ and τ individual types:
$[\![*\mathcal{R}(a)(b)]\!] = 1$ iff

a. $[\![a]\!]$ is the join of n objects $[\![a_1]\!], \ldots, [\![a_n]\!]$ ($n \geq 1$),
b. $[\![b]\!]$ is the join of m objects $[\![b_1]\!], \ldots, [\![b_m]\!]$ ($m \geq 1$),
c. for each $i \leq n$ exists some $j \leq m$ such that $[\![\mathcal{R}(a_i)(b_j)]\!] = 1$, and
d. for each $j \leq m$ exists some $i \leq n$ such that $[\![\mathcal{R}(a_i)(b_j)]\!] = 1$,

For example, the sentence Alice and Mary kissed John and Bill would be translated (without temporal information) as $*$**kiss**(**john** $\oplus$ **bill**)(**alice** $\oplus$ **mary**), entailing that each of Alice and Mary kissed (at least) one of John and Bill, and each of John and Bill was kissed by (at least) one of Alice and Mary – a cumulative reading. Temporal predicates with a single nominal argument (type eit) are binary relations, and thus they license cumulative readings between their nominal and temporal arguments.

3 Temporal generalized quantifiers

3.1 Plural temporal modifiers

Temporal modifiers denote temporal generalized quantifiers, which apply to temporal properties denoted by sentences (Pratt and Francez 1997, 2001; von Stechow 2002; Francez and Steedman to appear; Artstein 2005). We start with a simple case of temporal modification – an intransitive verb with a plural subject and a plural temporal modifier.

(19) The conferences ended on weekends.

We will assume that the definite article translates as the sum operator σ, which denotes the maximal element in the appropriate semilattice (Link 1983).

(20) $[\![\sigma x.P(x)]\!]$ is the maximal element which satisfies the formula $\lambda x.P(x)$, that is the unique element which satisfies the formula $\lambda x.\forall y[P(y) \rightarrow y \sqsubseteq x]$ (a plural individual).

(21) the conferences: $\sigma x.{*}\mathbf{conf}(x)$

Notice that conferences in (21) denotes a predicate of individuals, whereas meeting in (13) denoted a predicate of times. This difference is due to the nouns' syntactic contexts, which determines their semantic type – predicates of individuals when serving as verb arguments, and predicates of time intervals when serving as complements of temporal prepositions. In a richer ontology, conferences and meetings could denote events (see Artstein 2005, page 559; thanks to an anonymous reviewer for raising this point).

Predication is plural by default (cf. Landman 1996, 2000). Verbal predicates have a temporal argument, which is temporally included in the context of evaluation $\hat{\imath}$ and existentially quantified, as seen on the meaning of the one-place verbal predicate end.

(22) end: $\lambda x \lambda \hat{\imath}.\exists i'[i' \ {*}{\sqsubseteq}\ \hat{\imath} \wedge {*}\mathbf{end}(x)(i')]$

The constant **end** denotes a binary relation of type eit and inclusion '$\sqsubseteq$' is a binary relation of type iit, so the stars '$*$' in the above expression have the semantics as in (18).

The sentence the conferences ended receives the meaning representation (23) through straightforward function application.

(23) $\lambda \hat{\imath}.\exists i'[i' \ {*}{\sqsubseteq}\ \hat{\imath} \wedge {*}\mathbf{end}(\sigma x.{*}\mathbf{conf}(x))(i')]$

The constant **conf** is a unary predicate symbol, so the star '$*$' in front of it has the meaning as in (17).

The preposition on serves to indicate that the following noun phrase, weekends, is interpreted temporally. The temporal meaning of the common noun weekends is a predicate of time intervals, which translates as the plural of the constant **weekend** of type it.

(24) $\lambda i.{*}\mathbf{weekend}(i)$

The time interval i in the above expression needs to be temporally included in the overall context of evaluation, so the temporal context variable $\hat{\imath}$ is added by means of a contextualization operation, which maps any temporal property $\lambda i.J(i)$ to the function $\lambda i \lambda \hat{\imath}.i \ {*}{\sqsubseteq}\ \hat{\imath} \wedge J(i)$ – a relation between event times and context times.

(25) $\lambda i \lambda \hat{\imath}.i \ {*}{\sqsubseteq}\ \hat{\imath} \wedge {*}\mathbf{weekend}(i)$

For this example contextualization can be considered to be a lexical operation, but contextualization must also be allowed to happen outside the lexicon because it needs to apply to conjoined common nouns; more on this in section 4.

The variables i and $\hat{\imath}$ in the above representation range over both plural and singular (basic) intervals. The property denoted by (25) is true of an event time i and a context $\hat{\imath}$ if they are (plural) intervals consisting of (one or more) parts, such that each part of i

is a weekend and is included in (at least) one part of $\hat{\imath}$, and each part of $\hat{\imath}$ includes (at least) one part of i.

English allows indefinite plural NPs without a determiner, so weekends is also an NP which should have a generalized quantifier denotation; this is arrived at through the application of an implicit existential determiner meaning. Since weekends is a contextualized temporal common noun of type iit, it requires a (raised) temporal determiner of type $(iit)(it)it$ (26). The NP weekends thus denotes a *temporal* generalized quantifier (27).

(26) $\lambda I^{iit} \lambda J \lambda \hat{\imath}.\exists i[I(i)(\hat{\imath}) \wedge J(i)]$

(27) $\lambda J \lambda \hat{\imath}.\exists i[i \ast\!\subseteq \hat{\imath} \wedge \ast\mathbf{weekend}(i) \wedge J(i)]$

The preposition on itself, like during and other prepositions of temporal identity, denotes the identity function on temporal generalized quantifiers: such prepositions force a temporal reading of their complements, but do not provide a time-changing function like after or before. See Pratt and Francez (2001), Francez and Steedman (to appear), and Artstein (2005) for details. Therefore the meaning of the PP on weekends is the same temporal generalized quantifier (27) above.

Finally, temporal modification subordinates the temporal context of the main clause the conferences ended (23) to the temporal modifier on weekends (27) through straightforward function application.

(28) The conferences ended on weekends:
$$\lambda \hat{\imath}.\exists i[i \ast\!\subseteq \hat{\imath} \wedge \ast\mathbf{weekend}(i) \wedge \exists i'[i' \ast\!\subseteq i \wedge \ast\mathbf{end}(\sigma x.\ast\mathbf{conf}(x))(i')]]$$

The sentence is true in a context $\hat{\imath}$ if there exist (plural) intervals i and i', such that each conference ended on (at least) one part of i', each such part is a subinterval of (at least) one part of i, and each of those parts is a weekend and is included in the context $\hat{\imath}$. This entails that each of the conferences ended on a weekend. The indefinite NP weekends is not subject to a maximality condition, so there may well be weekends within the context $\hat{\imath}$ on which no conference ended.

The first conjunct $i \ast\!\subseteq \hat{\imath}$ in (28) allows for further temporal modification, leading to temporal 'cascades' (section 4). We interpret the variable $\hat{\imath}$ as the overall temporal context of evaluation; on the reasonable assumption that such contexts are singular (basic) intervals, the conjunct $i \ast\!\subseteq \hat{\imath}$ entails that all the individual intervals at which the conferences ended are subintervals of the temporal context of evaluation for the sentence.

The sentence the conferences ended on some weekends receives the exact same translation (28), because some denotes the temporal determiner (26) which was added implicitly in (27).

The sentence the conferences ended on the weekends requires a definite temporal determiner (29); this is equivalent to the Russellian definite determiner used in Pratt and Francez (2001) and Francez and Steedman (to appear) (see also Link 1983, page 318).

(29) the: $\lambda I^{iit} \lambda J \lambda \hat{\imath}.\exists i[(i = \sigma i''.I(i'')(\hat{\imath})) \wedge J(i)]$

This imposes a maximality requirement on the denotation of weekends, so the sentence is only true if some conference or other ended on each weekend in the context $\hat{\imath}$.

(30) The conferences ended on the weekends:
$$\lambda \hat{\imath}.\exists i[i = \sigma i''[i'' \ast\!\subseteq \hat{\imath} \wedge \ast\mathbf{weekend}(i'')] \wedge \exists i'[i' \ast\!\subseteq i \wedge \ast\mathbf{end}(\sigma x.\ast\mathbf{conf}(x))(i')]]$$

Finally, we can take all to denote a universal plural determiner.

(31) all: $\lambda I^{iit}\lambda J\lambda\hat{\imath}.\forall i[(i=\sigma i''.I(i'')(\hat{\imath}))\rightarrow J(i)]$

(32) The conferences ended on all weekends:
$\lambda\hat{\imath}.\forall i[i=\sigma i''[i''\ {*}{\subseteq}\ \hat{\imath}\wedge{*}\mathbf{weekend}(i'')]$
$\rightarrow\exists i'[i'\ {*}{\subseteq}\ i\wedge{*}\mathbf{end}(\sigma x.{*}\mathbf{conf}(x))(i')]]$

The truth conditions of this formula are similar to those of the previous one, except that it does not entail the existence of a weekend in the overall context of evaluation $\hat{\imath}$.

3.2 Conjoined temporal modifiers

We see cumulativity effects when the temporal modifier has coordinate plural common nouns. The natural language conjunction and has a cumulative denotation, defined in terms of the join operation '$\oplus$' on individuals: an object α is in the denotation of a coordinate expression if it is the join of two objects α_1 and α_2, where α_1 is in the denotation of the first conjunct and α_2 is in the denotation of the second (Link 1983; Krifka 1990a).

(33) and$^{(et)(et)(et)}$: $\lambda P\lambda Q\lambda x.\exists x_1,x_2[x=x_1\oplus x_2\wedge P(x_1)\wedge Q(x_2)]$
and$^{(it)(it)(it)}$: $\lambda I\lambda J\lambda i.\exists i_1,i_2[i=i_1\oplus i_2\wedge I(i_1)\wedge J(i_2)]$

The coordinate NP weekends and holidays is interpreted using this cumulative conjunction (34); the conjoined meaning is contextualized, and an existential determiner then turns it into a temporal generalized quantifier (35), which applies to the main clause (23) yielding the sentence meaning (36).

(34) $\lambda i.\exists i_1,i_2[i=i_1\oplus i_2\wedge{*}\mathbf{weekend}(i_1)\wedge{*}\mathbf{holiday}(i_2)]$

(35) $\lambda J\lambda\hat{\imath}.\exists i[i\ {*}{\subseteq}\ \hat{\imath}\wedge\exists i_1,i_2[i=i_1\oplus i_2\wedge{*}\mathbf{weekend}(i_1)\wedge{*}\mathbf{holiday}(i_2)]$
$\wedge J(i)]$

(36) The conferences ended on weekends and holidays:
$\lambda\hat{\imath}.\exists i[i\ {*}{\subseteq}\ \hat{\imath}\wedge\exists i_1,i_2[i=i_1\oplus i_2\wedge{*}\mathbf{weekend}(i_1)\wedge{*}\mathbf{holiday}(i_2)]$
$\wedge\exists i'[i'\ {*}{\subseteq}\ i\wedge{*}\mathbf{end}(\sigma x.{*}\mathbf{conf}(x))(i')]]$

The semantics of (36) is the desired meaning, which allows a cumulative relation between the temporal and nominal arguments: the sentence is true in a context $\hat{\imath}$ if there exist (plural) intervals i, i_1, i_2 and i' such that the following hold.

1. Each of the conferences ended on (at least) one part of i', each such part is a subinterval of (at least) one part of i, and each of those parts is either a part of i_1 (which is a weekend) or a part of i_2 (which is a holiday); this entails that each of the conferences ended on a weekend or on a holiday.

2. Each part of i_1 (which is a weekend) and each part of i_2 (which is a holiday) includes at least one part of i', and on each of those parts at least one conference ended; this entails that at least one of the conferences ended on a weekend, and one on a holiday.

(An additional requirement which is not modeled here is that there should be at least two conferences which ended on [different] weekends, and two which ended on [different] holidays; this follows if we take the plural morphemes on weekends and holidays to denote literal semantic plurality – the circled star '⊛' of Link (1983). See Artstein (2001) for an account of this phenomenon, called *multiple plurality*.)

We can also use cumulative conjunction between a singular indefinite and a plural indefinite, as in weekends and a holiday (37). This yields the desired representation when applied to a sentence like the conferences ended (38).

(37) $\lambda i.\exists i_1, i_2[i = i_1 \oplus i_2 \wedge *\mathbf{weekend}(i_1) \wedge \mathbf{holiday}(i_2)]$

(38) The conferences ended on weekends and a holiday:
$$\lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \wedge \exists i_1, i_2[i = i_1 \oplus i_2 \wedge *\mathbf{weekend}(i_1) \wedge \mathbf{holiday}(i_2)] \\ \wedge \exists i'[i' *\subseteq i \wedge *\mathbf{end}(\sigma x.*\mathbf{conf}(x))(i')]]$$

Exactly the same treatment is given to the expression Tuesday, Wednesday and Thursday in (1). The individual conjuncts will be translated as properties of intervals (type it): $\lambda i.\mathbf{Tue}(i)$, $\lambda i.\mathbf{Wed}(i)$, $\lambda i.\mathbf{Thu}(i)$. Constituents like every Tuesday or few Wednesdays show that such properties are true of all intervals which are Tuesdays or Wednesdays, but when translating bare day names these functions are true of only one particular day interval which is determined from context; how this interval gets chosen is a complicated matter which will not concern us here (for discussion see Kamp and Reyle 1993, page 614ff).

Cumulative conjunction gives the meaning of the coordinate expression (39), and contextualization and a determiner turn it into a temporal generalized quantifier (40), which applies to the main clause (41).

(39) $\lambda i.\exists i_1, i_2, i_3[i = i_1 \oplus i_2 \oplus i_3 \wedge \mathbf{Tue}(i_1) \wedge \mathbf{Wed}(i_2) \wedge \mathbf{Thu}(i_3)]$

(40)
$$\lambda J \lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \\ \wedge \exists i_1, i_2, i_3[i = i_1 \oplus i_2 \oplus i_3 \wedge \mathbf{Tue}(i_1) \wedge \mathbf{Wed}(i_2) \wedge \mathbf{Thu}(i_3)] \\ \wedge J(i)]$$

(41)
$$\lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \wedge \exists i_1, i_2, i_3[i = i_1 \oplus i_2 \oplus i_3 \wedge \mathbf{Tue}(i_1) \wedge \mathbf{Wed}(i_2) \wedge \mathbf{Thu}(i_3)] \\ \wedge \exists i'[i' *\subseteq i \wedge *\mathbf{end}(\sigma x.*\mathbf{conf}(x))(i')]]$$

The final representation allows for the desired cumulative relation: the sentence is true if there exist (plural) intervals i and i', such that each of the conferences ended on (at least) one part of i', each such part is a subinterval of (at least) one part of i, and each of those parts is Tuesday, Wednesday or Thursday – this entails that each conference ended on (at least) one of Tuesday, Wednesday and Thursday; also, each of Tuesday, Wednesday and Thursday is a part of i, each such part includes at least one part of i', and on each of those parts at least one conference ended – this entails that on each of Tuesday, Wednesday and Thursday, at least one of the conferences ended.

4 Temporal cascades

The temporal context variable $\hat{\imath}$ in (36) allows for further temporal modification, leading to temporal 'cascades' (Pratt and Francez 1997, 2001). Such cascades can also give rise to cumulative readings.

(42) In the winter and summer, the conferences ended on weekends and holidays.

The sentence has a cumulative reading, which allows for the possibility that none of the winter conferences ended on a holiday (as long as at least one of the summer conferences did). The entailments of this reading can be summarized as follows: (i) each of the conferences ended on a weekend or on a holiday in the winter or in the summer; (ii) at least one of the conferences ended on a weekend in the winter or summer and one on a holiday in the winter or summer; (iii) at least one of the conferences ended on a weekend or holiday in the winter and one on a weekend or holiday in the summer.

We derive this cumulative reading by coordinating and contextualizing the nouns winter and summer (43), turning the result into a temporal generalized quantifier with the determiner the (44), and applying this to the modified sentence the conferences ended on weekends and holidays (36).

(43) $\lambda i \lambda \hat{\imath}. i \ast\subseteq \hat{\imath} \wedge \exists i_1, i_2[i = i_1 \oplus i_2 \wedge \mathbf{winter}(i_1) \wedge \mathbf{summer}(i_2)]$

(44) $\lambda J \lambda \hat{\imath}. \exists i[i = \sigma i'[i' \ast\subseteq \hat{\imath} \wedge \exists i'_1, i'_2[i' = i'_1 \oplus i'_2 \wedge \mathbf{winter}(i'_1) \wedge \mathbf{summer}(i'_2)]] \wedge J(i)]$

(45) $\lambda J \lambda \hat{\imath}. \exists i[i = \sigma i'[i' \ast\subseteq \hat{\imath} \wedge \exists i'_1, i'_2[i' = i'_1 \oplus i'_2 \wedge \mathbf{winter}(i'_1) \wedge \mathbf{summer}(i'_2)]] \wedge \exists i''[i'' \ast\subseteq i \wedge \exists i''_1, i''_2[i'' = i''_1 \oplus i''_2 \wedge \ast\mathbf{weekend}(i''_1) \wedge \ast\mathbf{holiday}(i''_2)] \wedge \exists i'''[i''' \ast\subseteq i'' \wedge \ast\mathbf{end}(\sigma x.\ast\mathbf{conf}(x))(i''')]]]$

The formula (45) represents the desired cumulative reading: it is true if there exist (plural) intervals i, i'' and i''', such that all of the following hold:

1. Each of the conferences ended on (at least) one part of i''', each such part is a subinterval of (at least) one part of i'' (which is either a weekend or a holiday), and each of those parts is a subinterval of (at least) one part of i (which is either the winter or the summer); this entails that each of the conferences ended on a weekend or on a holiday in the winter or in the summer.

2. Each part of i'' includes (at least) one part of i''' (when at least one conference ended); since i'' is the sum of at least one weekend and one holiday, this entails that at least one of the conferences ended on a weekend (in the winter or summer) and one on a holiday (in the winter or summer).

3. Each of the winter and summer includes (at least) one part of i'' (a weekend or a holiday), which includes (at least) one part of i''' (when at least one conference ended); this entails that at least one of the conferences ended (on a weekend or holiday) in the winter and one (on a weekend or holiday) in the summer.

This meaning representation correctly allows for the possibility that perhaps in one of the seasons all the conferences ended on weekends, or on holidays. It is for this reason that contextualization must apply to the coordinate constituent weekends and holidays (34): if it applied earlier (for instance if common nouns were contextualized in the lexicon), then the condition $i'' \ast\subseteq i$ in (45) would be replaced by two separate conditions, $i''_1 \ast\subseteq i$ and $i''_2 \ast\subseteq i$. This would entail that in each of the winter and the summer, at least one conference ended on a weekend and one on a holiday, an entailment which is too strong.

(The latter entailment does obtain in a separate reading of the sentence, where winter and summer are conjoined by the familiar Boolean and. This results in a conjunction of two separate propositions, derived by applying each of the denotations of in the winter and in the summer to the meaning of the modified sentence (36).)

5 Coordinate temporal preposition phrases

Temporal generalized quantifier theory assumes that temporal preposition phrases, as a rule, denote temporal generalized quantifiers. Quantificational temporal PPs coordinated by Boolean conjunction do not give rise to cumulative readings: sentence (46) cannot be understood to mean that some of the conferences took place before most earthquakes and the others after a hurricane, and (47) cannot be understood to mean that some of the cookies are hidden inside every drawer and the others below most shelves. (Note the importance of the article the in the subjects of these sentences: without it we get a existential sentences which are interpreted with the familiar Boolean and on generalized quantifiers.)

(46)#The conferences took place before most earthquakes and after each hurricane.

(47)#The cookies are hidden inside every drawer and below most shelves.

The absence of cumulative readings for (46) and (47) can attributed to the absence of a general cumulative coordination scheme for generalized quantifiers (see Krifka 1990a for the difficulties of generalizing cumulative conjunction beyond property types). But coordinate PPs which are not quantificational do get cumulative interpretations: sentence (48) is true if each conference took place before an earthquake or after a hurricane, and likewise sentence (49) has a cumulative interpretation (locative modifiers are not analyzed in this paper).

(48) The conferences took place before earthquakes and after hurricanes.

(49) The cookies are hidden inside the washing machine and below the kitchen sink.

The availability of a cumulative interpretation of (48) suggest that the coordination of the PPs is at a lower type than that of generalized quantifiers.

Translations of temporal prepositions are formed using primitive temporal functions of type iii, which map an interval included in a context to a new interval (Pratt and Francez 1997, 2001; Francez and Steedman to appear; Artstein 2005).

(50) $\mathbf{before}(i, j)$ is the interval spanning from the beginning of i to the beginning of j, if $j \subseteq i$; undefined otherwise.

(51) $\mathbf{after}(i, j)$ is the interval spanning from the end of j to end of i, if $j \subseteq i$; undefined otherwise.

For this work, we generalize the meanings of temporal primitives to pluralities: $*\mathbf{before}$ maps a context i and a plural time interval $j = j_1 \oplus \cdots \oplus j_n$ to a different plural interval $\mathbf{before}(i, j_1) \oplus \cdots \oplus \mathbf{before}(i, j_n)$; after is treated in an analogous way (this is similar to the definition of plural roles in Landman 1996, 2000).

(52) $*\mathbf{before}(i, j)$ is the join of the intervals $\mathbf{before}(i, j')$ for all basic intervals $j' \sqsubseteq j$.

Previous work translated all temporal NPs as temporal generalized quantifiers; temporal prepositions were therfore translated as modifiers of temporal generalized quantifiers, that is as expressions of type $((it)it)(it)it$.

(53) before$^{((it)it)(it)it}$: $\lambda \mathcal{T}^{(it)it}.\lambda J \lambda \hat{\imath}.\mathcal{T}(\lambda i.J(*\mathbf{before}(\hat{\imath}, i)))(\hat{\imath})$

We will assume here that indefinite temporal noun phrases denote temporal properties of type it, and after contextualization they denote temporal relations between event times and context times of type iit; the type of temporal prepositions which modify such NPs is therefore $(iit)iit$. The following is the appropriate translation of the preposition before of the required type.

(54) before$^{(iit)iit}$: $\lambda J^{iit}\lambda i'\lambda\hat{\imath}.\exists i[J(i)(\hat{\imath}) \wedge i'{=}{*}\mathbf{before}(\hat{\imath}, i)]$

Applying the temporal relation modifier meaning of before (54) to a contextualized indefinite NP of type iit, followed by an existential determiner, gives identical results to applying the existential determiner first, followed by the temporal generalized quantifier modifier meaning of before (53). Let $\lambda i\lambda\hat{\imath}.i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{pred}(i)$ be an arbitrary plural temporal relation of type iit.

(55) a. $\lambda i'\lambda\hat{\imath}.\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{pred}(i) \wedge i'{=}{*}\mathbf{before}(\hat{\imath}, i)]$ before (54)
b. $\lambda J\lambda\hat{\imath}.\exists i'[\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{pred}(i) \wedge i'{=}{*}\mathbf{before}(\hat{\imath}, i)] \wedge J(i')]$ ∃-determiner
$= \lambda J\lambda\hat{\imath}.\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{pred}(i) \wedge J({*}\mathbf{before}(\hat{\imath}, i))]$

(56) a. $\lambda J\lambda\hat{\imath}.\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{pred}(i) \wedge J(i)]$ ∃-determiner
b. $\lambda J\lambda\hat{\imath}.\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{pred}(i) \wedge J({*}\mathbf{before}(\hat{\imath}, i))]$ before (53)

We will assume that expressions are always interpreted at the lowest available type (Partee and Rooth 1983; for a recent proposal about type shifting, see Winter (to appear)).

We now have the necessary machinery to account for the semantics of the coordinate temporal PPs in (48). The meaning of the preposition before (54) and its analogue after apply to the contextualized temporal NPs earthquakes and hurricanes.

(57) before earthquakes: $\lambda i'\lambda\hat{\imath}.\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{quake}(i) \wedge i'{=}{*}\mathbf{before}(\hat{\imath}, i)]$

(58) after hurricanes: $\lambda i'\lambda\hat{\imath}.\exists i[i \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{hurric}(i) \wedge i'{=}{*}\mathbf{after}(\hat{\imath}, i)]$

The coordinate PP before earthquakes and after hurricanes is interpreted through cumulative conjunction (33), raised to accommodate the extra temporal argument.

(59) and$^{(iit)(iit)(iit)}$: $\lambda I^{iit}\lambda J^{iit}\lambda i\lambda\hat{\imath}.\exists i_1, i_2[i = i_1 \oplus i_2 \wedge I(i_1)(\hat{\imath}) \wedge J(i_2)(\hat{\imath})]$

(60) $\lambda i'\lambda\hat{\imath}.\exists i'_1, i'_2[i' = i'_1 \oplus i'_2 \wedge \exists i_1[i_1 \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{quake}(i_1) \wedge i'_1{=}{*}\mathbf{before}(\hat{\imath}, i_1)]$
$\wedge \exists i_2[i_2 \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{hurric}(i_2) \wedge i'_2{=}{*}\mathbf{after}(\hat{\imath}, i_2)]]$

In order to act as a temporal modifier, the PP denotation must raise to the type of a generalized quantifier; this is achieved with an implicit existential determiner.

(61) $\lambda J\lambda\hat{\imath}.\exists i'[\exists i'_1, i'_2[i' = i'_1 \oplus i'_2$
$\wedge \exists i_1[i_1 \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{quake}(i_1) \wedge i'_1{=}{*}\mathbf{before}(\hat{\imath}, i_1)]$
$\wedge \exists i_2[i_2 \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{hurric}(i_2) \wedge i'_2{=}{*}\mathbf{after}(\hat{\imath}, i_2)]]$
$\wedge J(i')]$
$= \lambda J\lambda\hat{\imath}.\exists i_1, i_2[i_1 \oplus i_2 \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{quake}(i_1) \wedge {*}\mathbf{hurric}(i_2)$
$\wedge J({*}\mathbf{before}(\hat{\imath}, i_1) \oplus {*}\mathbf{after}(\hat{\imath}, i_2))]$

The resulting temporal generalized quantifier applies to the main clause.

(62) The conferences took place before earthquakes and after hurricanes.
$\lambda\hat{\imath}.\exists i_1, i_2[i_1 \oplus i_2 \; {*}{\subseteq} \; \hat{\imath} \wedge {*}\mathbf{quake}(i_1) \wedge {*}\mathbf{hurric}(i_2)$
$\wedge \exists i''[i'' \; {*}{\subseteq} \; {*}\mathbf{before}(\hat{\imath}, i_1) \oplus {*}\mathbf{after}(\hat{\imath}, i_2)$
$\wedge {*}\mathbf{take\text{-}place}(\sigma x.{*}\mathbf{conf}(x))(i'')]]]$

6 Coordinate temporal prepositions

Coordinate temporal prepositions can also give rise to cumulative readings.

(63) The conferences ended before and after a holiday.

(64) The cookies are hidden above and below the washing machine.

These sentences are true if some of the conferences ended before a certain holiday and some after it, or if some of the cookies are hidden above the washing machine and the others below it (additional readings are treated below).

Krifka (1990a) presents an analysis which applies to non-Boolean coordination of prepositions under the assumption that these denote modifier functions of a type that ends in t. In the semantics developed here, temporal prepositions are functions from contexts and intervals to other intervals. Faithful to the principle of interpreting expressions at the lowest possible type, we will assume that prepositions are coordinated at type iii.

(65) and$^{(iii)(iii)iii}$: $\lambda f \lambda g.\lambda i \lambda j. f(i, j) \oplus g(i, j)$

(66) before and after^{iii}: $\lambda i \lambda j.*\mathbf{before}(i, j) \oplus *\mathbf{after}(i, j)$

The coordinate PP before and after must raise to type $(iit)iit$ in order to apply to the contextualized meaning of a holiday (note that the noun holiday is singular, and the temporal predicate **holiday** is only true of atomic intervals).

(67) before and after$^{(iit)iit}$:
$\lambda J^{iit} \lambda i' \lambda \hat{\imath}.\exists i[J(i)(\hat{\imath}) \wedge i' = *\mathbf{before}(\hat{\imath}, i) \oplus *\mathbf{after}(\hat{\imath}, i)]$

(68) before and after a holiday:
$\lambda i' \lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \wedge \mathbf{holiday}(i) \wedge i' = *\mathbf{before}(\hat{\imath}, i) \oplus *\mathbf{after}(\hat{\imath}, i)]$

An existential determiner turns the result into a temporal generalized quantifier in order to act as a temporal modifier (69). This temporal generalized quantifier modifies the main clause, yielding the desired meaning (70).

(69) $\lambda J \lambda \hat{\imath}.\exists i'[\exists i[i *\subseteq \hat{\imath} \wedge \mathbf{holiday}(i) \wedge i' = *\mathbf{before}(\hat{\imath}, i) \oplus *\mathbf{after}(\hat{\imath}, i)] \wedge J(i')]$
$= \lambda J \lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \wedge \mathbf{holiday}(i) \wedge J(*\mathbf{before}(\hat{\imath}, i) \oplus *\mathbf{after}(\hat{\imath}, i))]$

(70) $\lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \wedge \mathbf{holiday}(i)$
$\wedge \exists i'[i' *\subseteq *\mathbf{before}(\hat{\imath}, i) \oplus *\mathbf{after}(\hat{\imath}, i) \wedge *\mathbf{end}(\sigma x.*\mathbf{conf}(x))(i')]]$

Coordinate temporal prepositions can result in additional readings. One reading of (63) is true if all the conferences ended before a holiday and after a (different) holiday. This reading can be derived using a Boolean, intersective interpretation of coordination which reduces conjunction at high types to propositional conjunction '$\wedge$' (see Francez and Steedman (to appear) for such a treatment of coordinate prepositions).

(71) $\lambda \hat{\imath}.\exists i[i *\subseteq \hat{\imath} \wedge \mathbf{holiday}(i) \wedge$
$\exists i''[i'' *\subseteq *\mathbf{before}(\hat{\imath}, i) \wedge *\mathbf{end}(\sigma x.*\mathbf{conf}(x))(i'')]]$
$\wedge \exists i'[i' *\subseteq \hat{\imath} \wedge \mathbf{holiday}(i') \wedge$
$\exists i'''[i''' *\subseteq *\mathbf{after}(\hat{\imath}, i') \wedge *\mathbf{end}(\sigma x.*\mathbf{conf}(x))(i''')]]$

Another reading is intermediate between the two readings above: it is true if some of the conferences ended before a certain holiday, while the others ended after a different holiday. This requires that the conjuction and be interpreted in a way that on the one hand distributes over the meaning of a holiday, and at the same time allows a cumulative relation with the subject. Such a meaning can be derived if we first shift the type of before and after to the temporal relation modifier type $(iit)iit$ (54), and then use a special conjunction for this type.

(72) and$^{((iit)iit)((iit)iit)(iit)iit}$: $\lambda F^{(iit)iit} \lambda G^{(iit)iit}.\lambda J^{iit}.F(J) \sqcup G(J)$

where $\sqcup$ is shorthand for the $(iit)(iit)(iit)$ meaning of and (59).

It is not clear what general principles about conjuction and type shifting motivate this particular meaning for conjuction; it does, however, yield the desired reading. Using this conjuction on the type-shifted preposition meanings gives the coordinate prepositions before and after a meaning of type $(iit)iit$ (73), which can then apply to the meaning of a holiday and then continue with a derivation similar to the one in section 5 to yield the final meaning (74).

(73) $\lambda J^{iit} \lambda i' \lambda \hat{\imath}.\exists i'_1, i'_2[i' = i'_1 \oplus i'_2 \wedge \exists i_1[J(i_1)(\hat{\imath}) \wedge i'_1{=}{*}\mathbf{before}(\hat{\imath}, i_1)]$
$\wedge \exists i_2[J(i_2)(\hat{\imath}) \wedge i'_2{=}{*}\mathbf{after}(\hat{\imath}, i_2)]]$

(74) $\lambda \hat{\imath}.\exists i_1, i_2[i_1 \oplus i_2 * \subseteq \hat{\imath} \wedge \mathbf{holiday}(i_1) \wedge \mathbf{holiday}(i_2)$
$\wedge \exists i''[i'' * \subseteq {*}\mathbf{before}(\hat{\imath}, i_1) \oplus {*}\mathbf{after}(\hat{\imath}, i_2) \wedge {*}\mathbf{end}(\sigma x.{*}\mathbf{conf}(x))(i'')]]$

7 Temporal clauses

Temporal context variables do not only mediate between a nominal argument and a temporal expression in the same clause, they also allow cumulative relations to percolate from one clause to another. Take sentence (10) from section 1.

(10) Andrew Johnson and Lyndon B. Johnson took office after Lincoln and Kennedy were assassinated.

The subject of the main clause and the subject of the dependent clause stand in a cumulative relation – the sentence is true in virtue of Andrew Johnson's succession of Lincoln and Lyndon B. Johnson's succession of Kennedy. The meaning representation for the sentence is derived as follows. We assume that proper names denote constants of type *e*, and that the conjunction and at this type denotes the join operation on the domain of entities (Link 1983; Krifka 1990a). The matrix clause interpretation is straightforward.

(75) Andrew Johnson and Lyndon B. Johnson took office:
$\lambda \hat{\imath}.\exists i'[i' * \subseteq \hat{\imath} \wedge {*}\mathbf{take\text{-}office}(\mathbf{aj} \oplus \mathbf{lbj})(i')]$

The dependent clause forms a temporal generalized quantifier through the application of an implicit temporal determiner (Pratt and Francez 1997, 2001).

(76) after Lincoln and Kennedy were assassinated:
$\lambda J \lambda \hat{\imath}.\exists i[i * \subseteq \hat{\imath} \wedge {*}\mathbf{be\text{-}assasinated}(\mathbf{al} \oplus \mathbf{jfk})(i) \wedge J({*}\mathbf{after}(\hat{\imath}, i))]$

This temporal generalized quantifier applies to the matrix clause.

(77) Andrew Johnson and Lyndon B. Johnson took office after Lincoln and Kennedy were assassinated:
$\lambda\hat{\imath}.\exists i[i \ast\subseteq \hat{\imath} \wedge \ast\textbf{be-assasinated}(\textbf{al} \oplus \textbf{jfk})(i)$
$\wedge \exists i'[i' \ast\subseteq \ast\textbf{after}(\hat{\imath}, i) \wedge \ast\textbf{take-office}(\textbf{aj} \oplus \textbf{lbj})(i')]]$

The representation in (77) now reads as follows: there exist (plural) intervals i and i', such that each of Andrew Johnson and Lyndon B. Johnson took office in (at least) one part of i', each such part is after (at least) one part of i, and in each of those parts (at least) one of Lincoln and Kennedy was assassinated; and each of Lincoln and Kennedy was assassinated in (at least) one part of i, each such part is followed by (at least) one part of i', and in each of those parts (at least) one of Andrew Johnson and Lyndon B. Johnson took office. This is indeed the desired cumulative reading.

We see that cumulative relations between arguments of a main clause and a temporal modifier clause follow from the semantics that allows cumulative relations between nominal arguments and temporal modifiers within a clause, without the need for additional machinery. This is because semantically, temporal clauses are temporal generalized quantifiers. The mediation of temporal context variables explains why temporal clauses are not subject to the generalization of Sauerland (1998), Beck (2000), and Beck and Sauerland (2000), that cumulative relations are sensitive to locality constraints. According to the above works, when two NPs are not coarguments of the same verb, a cumulative relation between them only obtains as the result of a process of complex predicate formation. For example, the sentence Sue and Amy discussed a review of two new books allows a cumulative relation between the NPs Sue and Amy and two new books because of the possibility of forming the complex predicate "discussed a review of" (Beck and Sauerland 2000, example 50a, page 366). Such complex predicate formation is subject to locality restrictions, so we do not expect it to be possible to form a predicate like "took office after … was assassinated". Indeed, under the semantics proposed here, cumulative relations between arguments of a main clause and a temporal clause do not arise through the formation of a complex predicate, but rather are mediated by the temporal context variables within each clause.

An anonymous reviewer raises the following question: why does the mechanism proposed in this paper not generalize to allow cumulative relations between arguments in a main clause and a complement clause? That is, why is the following sentence still subject to Beck and Sauerland's generalization about the locality of cumulative relations?

(78) Andrew Johnson and Lyndon B. Johnson realized that Lincoln and Kennedy were great presidents.

It appears that a formal system could be devised which would derive the undesired reading, with a cumulative relation between the subjects of the main clause and the complement clause. However, natural language does not seem to behave this way, which implies that propositional complements and clausal temporal modifiers have different representations with regard to plurality. The following paragraphs are an attempt to characterize this difference more precisely.

We start with the observation that in contrast to sentence (78) which lacks a cumulative reading, sentence (79) with conjoined sentential complements does have a cumulative reading – it is true if Andrew Johnson realized that Lincoln was a great president and Lyndon B. Johnson realized that Kennedy was a great president.

(79) Andrew Johnson and Lyndon B. Johnson realized that Lincoln was a great president and that Kennedy was a great president.

We see that conjunction reduction does not apply to cumulative conjunction – a proposition with a cumulatively conjoined subject is not the same as the cumulative conjunction of the respective propositions formed with the individual conjuncts as subjects. This needs to be captured in a formal semantics.

We assume that verbs like realize take propositions (sentence intensions) as complements, that propositions are sets of possible worlds, and we use a logical language with explicit abstraction over world variables. For simplicity, we also omit all references to times. The complement of realize in (78) would receive the following translation.

(80) that Lincoln and Kennedy were great presidents:
$\lambda w.{*}\mathbf{great\text{-}pres}(\mathbf{al} \oplus \mathbf{jfk})(w)$

The formula in (80) denotes a set of worlds. But which worlds? Given the difference between (78) and (79), these should only be the worlds in which both Lincoln and Kennedy were great presidents, that is the set of worlds denoted by the following formula.

(81) $\lambda w.\mathbf{great\text{-}pres}(\mathbf{al})(w) \wedge \mathbf{great\text{-}pres}(\mathbf{jfk})(w)$

The equivalence between (80) and (81) follows from the (lexical) fact that "be a great president" is a predicate that distributes to all of its atoms, but only if the variable w is limited to individual worlds. If w were allowed to range over pluralities of possible worlds, then (80) would also include, say, the join of a world in which Lincoln but not Kennedy is a great president and a world in which Kennedy but not Lincoln is a great president. Our provisional conclusion, then, is that possible worlds do not form plurality structures the same way that individuals and times do.

We still do not have an account of the cumulative conjunction of propositions in (79), and it may be that pluralities of possible worlds could play a useful role there. But developing a theory of plural worlds which preserves the current insights of intensionality theory is a matter which exceeds the scope of this article. All we can say at this point is that possible worlds do not appear to behave like individuals, events, times, and locations with respect to plurality, and that further investigation is needed.

8 Conclusion

This paper described an extension to temporal generalized quantifier theory which allows treatment of plural expressions (both nominal and temporal), and correctly captures cumulative relations between arguments and modifiers. The extension mostly consists of a straightforward application of the semilattice structures of Link (1983) to represent plurality, and the mechanism of Scha (1981) and Krifka (1990a) for capturing cumulative inferences. The proposed system departs from previous works on temporal generalized quantifier theory (Pratt and Francez 1997, 2001; von Stechow 2002; Francez and Steedman to appear; Artstein 2005) in the following two aspects.

1. Temporal prepositions are allowed to have denotations at a lower type than modifiers of temporal generalized quantifiers (type $((it)it)(it)it)$. This is necessary in order to correctly characterize cumulative relations brought about by the coordination of temporal prepositions and PPs (sections 5 and 6).

2. Contextualization, the operation which transforms a predicate of times to a relation between event times and context times, must sometimes apply as part of the

semantic derivation and not as a lexical operation. This allows for cumulative relations over a long 'cascade' of temporal modifiers (section 4).

The semantics also correctly allows for cumulative relations between arguments of a main clause and a temporal modifier clause. This is achieved without violating locality restrictions on the accessible domains of cumulative readings.

Acknowledgments

We thank two anonymous reviewers, Ariel Cohen, Veneeta Dayal, Edit Doron, Yael Greenberg, Irene Heim, Fred Landman, Anita Mittwoch, Susan Rothstein, Roger Schwarzschild, Yael Sharvit, Arnim von Stechow, and the participants of the Fourteenth Amsterdam Colloquium. Thanks to Nancy Hall for supplying many English judgments. During the period this research took place, the first author was a postdoctoral fellow at the Laboratory for Computational Linguistics, Department of Computer Science, Technion – Israel Institute of Technology. We gratefully acknowledge support from the Israel Science Foundation (FIRST program, grant #15/99, Principal Investigator: Nissim Francez, co-PI: Yoad Winter), a postdoctoral fellowship from the Technion – Israel Institute of Technology (first author), and the Technion vice-president's fund for the promotion of research (second author).

References

Artstein, R.: 2001, 'Conjunction Weakening and Morphological Plurality', in K. Megerdoomian and L. A. Bar-el (eds.), *WCCFL 20 Proceedings*, Cascadilla Press, Somerville, MA, pp. 29–42.

Artstein, R.: 2005, 'Quantificational Arguments in Temporal Adjunct Clauses', *Linguistics and Philosophy* **28**(5), 541–597.

Artstein, R. and N. Francez: 2003, 'Plural Times and Temporal Modification', in P. Dekker and R. van Rooy (eds.), *Proceedings of the Fourteenth Amsterdam Colloquium*, ILLC, University of Amsterdam, pp. 63–68.

Beck, S.: 2000, 'Star Operators. Episode 1: Defense of the Double Star', in K. Kusumoto and E. Villalta (eds.), *Issues in Semantics* (*University of Massachusetts Occasional Papers* 23), GLSA, Amherst, MA, pp. 1–23.

Beck, S. and U. Sauerland: 2000, 'Cumulation is Needed: A Reply to Winter (2000)', *Natural Language Semantics* **8**(4), 349–371.

Francez, N. and M. Steedman: to appear, 'Categorial Grammar and the Semantics of Indexical Preposition Phrases', *Linguistics and Philosophy* .

Groenendijk, J., T. M. V. Janssen and M. Stokhof (eds.): 1984, *Truth, Interpretation and Information: Selected Papers from the Third Amsterdam Colloquium* (*Groningen-Amsterdam Studies in Semantics* 2), Foris, Dordrecht.

Kamp, H. and U. Reyle: 1993, *From Discourse to Logic: Introduction to Modeltheoretic Semantics of Natural Language, Formal Logic and Discourse Representation Theory* (*Studies in Linguistics and Philosophy* 42), Kluwer, Dordrecht.

Krifka, M.: 1990a, 'Boolean and Non-Boolean "And"', in L. Kálmán and L. Pólos (eds.), *Papers from the Second Symposium on Logic and Language*, Akadémiai Kiadó, Budapest, pp. 161–188.

Krifka, M.: 1990b, 'Four Thousand Ships Passed Through the Lock: Object-Induced Measure Functions on Events', *Linguistics and Philosophy* **13**(5), 487–520.

Landman, F.: 1989, 'Groups, I', *Linguistics and Philosophy* **12**(5), 559–605.

Landman, F.: 1996, 'Plurality', in S. Lappin (ed.), *The Handbook of Contemporary Semantic Theory*, chap. 16, Blackwell, Oxford, pp. 425–457.

Landman, F.: 2000, *Events and Plurality: The Jerusalem Lectures* (*Studies in Linguistics and Philosophy* 76), Kluwer, Dordrecht.

Link, G.: 1983, 'The Logical Analysis of Plurals and Mass Terms: A Lattice-Theoretical Approach', in R. Bäuerle, C. Schwarze and A. von Stechow (eds.), *Meaning, Use and Interpretation of Language*, de Gruyter, Berlin, pp. 302–323.

Partee, B. H. and M. Rooth: 1983, 'Generalized Conjunction and Type Ambiguity', in R. Bäuerle, C. Schwarze and A. von Stechow (eds.), *Meaning, Use and Interpretation of Language*, de Gruyter, Berlin, pp. 361–383.

Pratt, I. and N. Francez: 1997, 'On the Semantics of Temporal Prepositions and Preposition Phrases', Tech. Rep. UMCS-97-4-2, Department of Computer Science, University of Manchester, ftp://ftp.cs.man.ac.uk/pub/TR/UMCS-97-4-2.ps.Z.

Pratt, I. and N. Francez: 2001, 'Temporal Prepositions and Temporal Generalized Quantifiers', *Linguistics and Philosophy* **24**(2), 187–222.

Sauerland, U.: 1998, 'Plurals, Derived Predicates, and Reciprocals', in U. Sauerland and O. Percus (eds.), *The Interpretive Tract* (*MIT Working Papers in Linguistics* 25), MIT Department of Linguistics and Philosophy, Cambridge, MA, pp. 177–204.

Scha, R. J. H.: 1981, 'Distributive, Collective and Cumulative Quantification', in J. Groenendijk, T. M. V. Janssen and M. Stokhof (eds.), *Formal Methods in the Study of Language, Part 2* (*Mathematical Centre Tracts* 136), Mathematisch Centrum, Amsterdam, pp. 483–512, reprinted in Groenendijk *et al.* (1984), pp. 131–158.

Schwarzschild, R.: 1994, 'Plurals, Presuppositions and the Sources of Distributivity', *Natural Language Semantics* **2**(3), 201–248.

von Stechow, A.: 2002, 'Temporal Prepositional Phrases with Quantifiers: Some Additions to Pratt and Francez (2001)', *Linguistics and Philosophy* **25**(5–6), 755–800.

Sternefeld, W.: 1998, 'Reciprocity and Cumulative Predication', *Natural Language Semantics* **6**(3), 303–337.

Winter, Y.: 2000, 'Distributivity and Dependency', *Natural Language Semantics* **8**(1), 27–69.

Winter, Y.: to appear, 'Type Shifting with Semantic Features: A Unified Perspective', in C. Barker and P. Jacobson (eds.), *Direct Compositionality*, Oxford University Press, Oxford.