Quantificational arguments in temporal adjunct clauses

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Abstract. Quantificational arguments can take scope outside of temporal adjunct clauses, in an apparent violation of locality restrictions: the sentence *few secretaries cried after each executive resigned* allows the quantificational NP *each executive* to take scope above *few secretaries*. I show how this scope relation is the result of local operations: the adjunct clause is a temporal generalized quantifier which takes scope over the main clause (Pratt and Francez 2001), and within the adjunct clause, the quantificational argument takes scope above the implicit determiner which forms the temporal generalized quantifier. The paper explores various relations among quantificational arguments across clause boundaries, including temporal clauses that are modified internally by a temporal adverbial and temporal clauses with embedded sentential complements.

1. Introduction

Temporal clauses provide apparent counterexamples to the generalization that adjunct clauses form boundaries for quantifier scope. The sentences in (1) have readings where the quantificational argument of the embedded clause takes wide scope with respect to the matrix subject: the sentences are true if each resignation or termination is associated with different crying secretaries.

$$\text{(1)}\quad \left\{\begin{array}{l}\text{A secretary}\\ \text{Few secretaries}\end{array}\right\} \text{cried} \left\{\begin{array}{l}\text{before}\\ \text{when}\\ \text{after}\end{array}\right\} \left\{\begin{array}{l}\text{each executive resigned.}\\ \text{the board fired each executive.}\end{array}\right\}$$

Such readings are generally not available with non-temporal adjunct clauses: the sentences in (2) do not allow a wide-scope interpretation of the embedded argument.

$$\text{(2)}\quad \left\{\begin{array}{l}\text{A secretary}\\ \text{Few secretaries}\end{array}\right\} \text{cried} \left\{\begin{array}{l}\text{if}\\ \text{although}\\ \text{because}\end{array}\right\} \left\{\begin{array}{l}\text{each executive resigned.}\\ \text{the board fired each executive.}\end{array}\right\}$$

The ability of a quantificational argument to take scope outside of a temporal adjunct clause therefore appears to be related to the temporality of the clause. In this paper I show how this falls naturally from a semantics that treats temporal adjunct clauses as temporal generalized quantifiers (Pratt and Francez 2001). Temporal adjunct clauses become temporal generalized quantifiers through the application of a temporal determiner, akin to the explicit determiner in PPs such as *before/during/after each meeting*. The determiner applies within the adjunct clause, so a quantificational argument can take scope over it; in turn, the entire temporal generalized quantifier can take scope above a quantifier in the matrix clause, giving the quantificational argument scope over the matrix clause as well. Through this mechanism the scope of a quantificational argument transcends the clause that contains it without violating locality restrictions.

A further illustration of the scopal properties of quantificational arguments in temporal adjunct clauses is the ability of a quantifier inside such a clause to bind a pronoun outside it. The sentences in (3) all have such readings, which can be roughly paraphrased as "for each boy, before/when/after he goes to sleep, I give him a kiss".

(3) $\left\{\begin{array}{l}\text{Before}\\ \text{When}\\ \text{After}\end{array}\right\}$ each boy goes to sleep, I give him a kiss.

While superficially similar to "donkey" sentences like *if a farmer owns a donkey he beats it*, the above sentences must be instances of true variable binding because universal quantifiers do not license "donkey" readings: the sentences in (4) do not have readings that can be paraphrased as "for each boy, if/although/because he goes to sleep, I give him a kiss".

(4) $\left\{\begin{array}{l}\text{If}\\ \text{Although}\\ \text{Because}\end{array}\right\}$ each boy goes to sleep, I give him a kiss.

Evidence that the contrast between (3) and (4) stems from the temporality of the subordinate clause comes from looking at atemporal *when*-clauses such as (5) (Carlson 1979, Farkas and Sugioka 1983).

(5) When a bear has blue eyes she is intelligent.

The atemporal *when*-clause in (5) allows a "donkey" interpretation of its subject *a bear*, but a universal quantifier in this position cannot bind a pronoun outside of its clause—sentence (6) is incoherent; when the word *when* has a temporal interpretation, a universally quantified argument can bind a pronoun outside the adjunct clause (7).

(6)*When each bear has blue eyes she is intelligent.

(7) When each bear is hungry she growls.

My discussion will concentrate on examples with scope ambiguities like (1) above, and ignore pronoun-binding sentences like (3). While the ability to bind a pronoun in the main clause is one of the clearest illustrations of the scope-taking ability of quantifiers in temporal adjunct clauses, the question of how a pronoun gets bound is orthogonal to the problem of quantifier scope: once our semantics gets the scope right, the binding of pronouns should follow from any theory of pronoun interpretation.

The ability of quantificational arguments to take scope outside the temporal adjunct clauses that contain them is not a peculiar trait of English; however, it is not universal. Hebrew behaves like English, and in the examples below, the quantificational arguments in the temporal adjunct clause may receive wide scope.

$$\text{(8)}\quad \left\{\begin{array}{lll} \text{mazkira} & & \text{bax-ta} \\ \text{secretary} & & \text{cried-sg} \\ \text{mazkirot} & \text{sfurot} & \text{bax-u} \\ \text{secretaties} & \text{few} & \text{cried-pl} \end{array}\right\} \left\{\begin{array}{ll} \text{lifnei} & \text{še} \\ \text{before} & \text{that} \\ \text{kše} & \\ \text{when} & \\ \text{axrei} & \text{še} \\ \text{after} & \text{that} \end{array}\right\} \left\{\begin{array}{llll} \text{kol} & \text{menahel} & \text{hitpater} & \\ \text{each} & \text{manager} & \text{resigned} & \\ \text{ha-direktoryon} & \text{piter} & \text{kol} & \text{menahel} \\ \text{the-board} & \text{fired} & \text{each} & \text{manager} \end{array}\right\}$$

German, on the other hand, does not allow quantificational arguments to take scope outside temporal adjunct clauses. In the end of section 3.2 I suggest that the difference can be attributed to morphology: while English and Hebrew employ an implicit temporal determiner, in German the temporal determiner constitutes part of the meaning of the complementizer, and therefore a quantificational argument cannot take scope above it while remaining within the boundaries of the adjunct clause.

Due to the recent interest in temporal quantification (Pratt and Francez 2001, von Stechow 2002, Francez and Steedman to appear), I feel that it is appropriate to add a note that places this work in relation to the others. Pratt and Francez introduce temporal context variables and temporal generalized quantifiers, and use them mainly for an account of temporal “cascades”—the modification of a sentence by multiple temporal adverbials—as in *Bill cried during every meeting on Tuesday*. The theory is extended by von Stechow to include temporal relations brought about by tense and aspect, and reformulated into a framework of transparent LF. Francez and Steedman extend the analysis to deal with locative prepositions and with varying orders of temporal and locative modifiers, reformulating it in the framework of Combinatory Categorial Grammar.

The present study is a detailed investigation of relations between quantificational arguments across the boundaries of temporal adjunct clauses. Temporal adjunct clauses are treated in all of the above works, but quantifiers within such clauses only receive a cursory mention in one of them (Francez and Steedman, section 5.1). In my investigation I largely ignore matters of tense and aspect; while I agree with von Stechow’s claim that “an adequate treatment of temporal adverbs is only possible on the basis of an elaborate theory of tense and aspect" (2002:756), I find tense and aspect orthogonal to the problems of quantification discussed in this paper, so I set these questions aside in the interest of keeping the investigation focused. I also ignore Francez and Steedman's extension to locatives. Locative clauses allow quantifier scope interactions with the main clause just like temporal clauses (thanks to Anita Mittwoch for this observation).

(9) A tree grows where each car had crashed.

Avoiding locative clauses in this paper is done only in the interest of keeping the semantics simple; it appears that an extension along the lines of Francez and Steedman (to appear) is possible. We should note that locative clauses are comparatively rare—unlike their temporal counterparts, locative prepositions like *over*, *under*, *behind* etc. do not take clausal complements. This property of locative prepositions appears to be valid crosslinguistically, and it does not receive an explanation; the mystery, however, is independent of the ability of quantifier scope to cross the boundaries of both temporal and locative clauses.

The paper is organized as follows: section 2 develops the basic theory of temporal generalized quantifiers, and is mostly a reinterpretation of ideas presented in the three works mentioned above. The heart of the paper lies in section 3, which examines scope interactions across the boundaries of temporal clauses. The main insight on how a quantificational argument escapes the scope of its clause is developed in sections 3.1 and 3.2; section 3.3 looks at restrictions on the resulting readings, and section 3.4 extends the treatment to temporal clauses which have temporal modifiers within them. Section 4 compares the theory developed in this paper to the other works on the topic, and offers two mild arguments in favor of the current formalism. Section 5 offers a summary and conclusion.

2. The basic theory of temporal modification

I develop a theory of temporal modification based on the proposals of Pratt and Francez (1997, 2001), von Stechow (2002) and Francez and Steedman (to appear). These works develop similar semantic systems using significantly different formalisms for the syntax-semantics interface: Pratt and Francez leave the interface unspecified, von Stechow uses a syntax with movement operations and abstract logical forms, and Francez and Steedman use a highly lexicalized Combinatory Categorial Grammar. The contribution of the present paper is mostly on the side of the semantics: I show how the semantics of temporal modification allows a quantifier to escape from what would otherwise be a scope island. As far as the syntax is concerned, I choose the middle way: I assume a fairly close match between surface form and semantic interpretation, but I will introduce certain semantic operations that take place at various nodes of the surface representation which are not triggered by morphology or syntax. This results in a system that overgenerates meanings, and in order to restrict the system I will posit a number of constraints on semantic derivations. Such restrictions would fit in the syntactic component of von Stechow's framework and in the lexicon of Francez and Steedman's framework. At the end of the paper, in section 4, I will show how my formulation is better at handling two particular structures, namely non-persistent temporal predicates and long-distance temporal dependencies.

2.1. PRELIMINARIES

I use a two-sorted translation language with lambda abstraction (cf. Gallin 1975), which represents times explicitly: *e* is the type of individuals and *i* of time intervals. To keep the language simple, I will treat what are ordinarily thought of as event predicates as if they are predicates of time intervals; this will allow us to eliminate events from our ontology and to simplify expressions of the form $\lambda i.\exists e[i = \tau(e) \wedge \mathbf{pred}(e)]$ to the more readable form $\lambda i.\mathbf{pred}(i)$. Verbs and temporal nouns have temporal arguments, akin to event arguments in event semantics. The basic meaning of a verb like *cry* is a relation between individuals and time intervals $\lambda x \lambda i.\mathbf{cry}(x)(i)$ (type eit), and a noun like *meeting* in a temporal context is a property of time intervals $\lambda i.\mathbf{meeting}(i)$ (type it)—those time intervals during which a meeting takes place.

Representations are enriched by temporal context variables, which are variables of type *i* that stand for time frames for the evaluation of sentences (cf. Pratt and Francez 2001). These can occur as free variables, and as such they are treated as indexicals whose meaning is determined by an assignment function. The existence of temporal indexicals has been recognized at least since Partee (1973), who notes that a sentence like *I didn't turn off the stove* makes reference to "a definite interval whose identity is generally clear from extralinguistic context" (pages 602–603). The most common use of free temporal context variables in this article will be to denote the overall temporal context of evaluation. Temporal indexing applies to both nouns and verbs (cf. Enç 1986), so both will allow temporal context variables in their representations.

Temporal modification means subordinating the temporal context of a particular linguistic expression to that of another expression; this is captured in our representation by binding the temporal context variable of the temporally subordinate expression. This treatment of temporal indices is formally similar to the treatment of world indices in Groenendijk and Stokhof (1982), where free world variables get bound in forming intensions of sentences, but binding of an index has a different meaning in our semantics—it does not result in an intension, but rather in the creation of a temporal property (see example (24) in section 2.3).

A few typographical conventions: constants like **cry** are set in **boldface**, and variables are set in *italics*. I use lower case letters for individual variables and upper case letters for property variables; the following letters (with primes, if necessary) stand for variables of the most commonly used types.

type e: x, y	type et: P, Q
type i: i, j	type it: I, J

The types of higher-order variables will be noted explicitly with superscripts when needed, e.g. $\mathcal{T}^{(it)t}$. A distinguished temporal context variable stands for the overall temporal context of evaluation, and it is marked with a hat in order to make it visually salient: $\hat{\imath}$.

2.2. Basic sentence meanings

Natural language predicates are indexed to time intervals. An intransitive verb like *cry* denotes a relation between individuals and time intervals (type eit); the denotation we get for a sentence like *Bill cried* is a property of time intervals—the set of times at which Bill cried (I ignore tense for the moment, postponing the discussion to section 2.5).

(10) cry $\rightsquigarrow \lambda x \lambda i.\mathbf{cry}(x)(i)$

(11) Bill cried $\rightsquigarrow \lambda i.\mathbf{cry}(\mathbf{bill})(i)$

The sentence *Bill cried* is true if a time that satisfies (11) exists within the general time frame in which the sentence is evaluated. We will capture these truth conditions by altering the representation in (11), subjecting it to two operations that apply in succession: *contextualization* (12a) introduces the temporal context variable $\hat{\imath}$ which stands for the context of evaluation, and *existential closure* (13a) closes off the event time variable by turning the lambda operator into an existential quantifier (the latter is akin to the existential closure of an event argument in event semantics).

(12) a. Contextualization operation (type $(it)it$): $\lambda I \lambda i.i \subseteq \hat{\imath} \wedge I(i)$

b. Bill cried $\rightsquigarrow \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{cry}(\mathbf{bill})(i)$

(13) a. Existential closure operation (type $(it)t$): $\lambda I.\exists i[I(i)]$

b. Bill cried $\rightsquigarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{cry}(\mathbf{bill})(i)]$

The final representation (13b) is the translation of the sentence *Bill cried*; it is true with respect to a model M and an evaluation context $\hat{\imath}$ if there exists an interval i included in $\hat{\imath}$ such that Bill cried at i in M.

An alternative to the operations (12a) and (13a) would be to define truth directly on the representation (11). Since context of evaluation is not represented explicitly in (11) we would need an indirect mechanism for specifying the truth conditions, perhaps along the lines of the following definition of truth with respect to one index of evaluation ("true_1") in terms of truth with respect to two indices of evaluation (Dowty 1982:33, example 24).

(14) $[\![\phi]\!]^j = 1$ ('ϕ is true_1 at j') iff there is some i such that $[\![\phi]\!]^{i,j} = 1$.

But such a definition will not do for our purposes. Dowty's definition is part of an account of tense, aspect, and non-quantificational temporal modifiers, and thus it can allow one index to always receive implicit existential quantification at the sentence level. This paper is concerned with quantificational temporal modifiers; these operate on the temporal context of linguistic expressions, and in order to make context accessible to various quantifiers it must be represented in the translation explicitly.

The idea that temporal modifiers operate on the context (or "reference time") of modified expressions rather than on their event time appears at least as early as Dowty (1982). The reasons are discussed in detail in Pratt and Francez (2001:200–206), so here I will just repeat the crux of the argument. Modifying the event time, as done for instance in Dowty (1979) or Stump (1985), works fine with non-quantificational temporal modifiers, as in the following example from Stump (1985:103).

(15) Yesterday John saw Mary in the morning, after bill arrived.

The temporal modifiers can apply in turn to a temporal property formed by abstracting over the event time of the verb; this results in a series of conjoined temporal predicates that do not stand in a scope relation to one another.

But when temporal modifiers are quantificational, they do stand in scope relations: in the following example, the modifier *during most conferences* takes scope above *after each meeting*.

(16) John saw Mary after each meeting during most conferences

In order to allow scoped relations, each modifier has to apply to a distinct temporal variable, but the verb (or any other temporal predicate) only has one event time. Temporal modifiers must therefore operate on something other than the event time of the expression they modify, and this is the context. Since each modifier introduces its own context, the number of modifiers is in principle unlimited and leads to the phenomenon of "cascading" (Pratt and Francez 2001, see also section 2.8 below). The fact that the scope of temporal modifiers does not necessarily follow their surface order is treated by Francez and Steedman (to appear) using the power of Combinatory Categorial Grammar, and will not be discussed here.

The inclusion relation between the event time and context is similar to the relation proposed by Kamp and Reyle (1993) between an eventuality and the discourse referent which plays the role of its "location time". Temporal inclusion of an event time in its context is considered by von Stechow (2002:sections 10–11) to be the meaning of perfective aspect. In order to avoid the complications raised by aspectual class, I will always choose examples with predicates for which inclusion is the appropriate relation. Contextualization must precede existential closure because it has to apply at a point where the time variable of the predicate is accessible.

2.3. Temporal generalized quantifiers

Temporal modifiers like the PP *after each meeting* are temporal generalized quantifiers of type $(it)t$. I take common nouns like *meeting* to denote predicates of times rather than predicates of events when placed in a temporal context, e.g. as the complement of a temporal preposition; the temporal noun *meeting* is a predicate of type it.

(17) meeting $\rightsquigarrow \lambda i.\mathbf{meeting}(i)$

A predicate like *meeting* is itself evaluated with respect to the overall temporal context, so the temporal context variable $\hat{\imath}$ is introduced by the contextualization operation.

(18) meeting $\rightsquigarrow \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)$

The determiner *each* in a temporal NP like *each meeting* is similar to the familiar nominal determiner *each*, except that it denotes a relation between predicates of times rather than predicates of individuals—it is of type $(it)(it)t$ rather than type $(et)(et)t$. *Each* combines with the contextualized translation of the noun *meeting* in the obvious way.

(19) each $\rightsquigarrow \lambda I \lambda J.\forall i[I(i) \rightarrow J(i)]$

(20) each meeting $\rightsquigarrow \lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow J(i)]$

Since the common noun *meeting* was taken to be a predicate of times, it should come as no surprise that the expression *each meeting*, when placed in a temporal context, denotes a temporal generalized quantifier, that is a predicate of predicates of times.

The temporal preposition *after* translates as a function of type $((it)t)(it)t$, mapping temporal generalized quantifiers to temporal generalized quantifiers; this higher-order function is defined using the primitive temporal function $\lambda i \lambda j.\mathbf{after}_i(j)$ from interval pairs to intervals (type iii; the same function is called "time-from" in Pratt and Francez 2001, and F_{after} in Francez and Steedman to appear).

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

The proposition that an interval j' follows j (within a context i) can be expressed by the formula $j' \subseteq \mathbf{after}_i(j)$. I will discuss the rationale for this treatment of preposition meanings in section 2.6, after we have seen how these meanings are put into use by the semantics.

As for the higher-order translation of the preposition *after*, we note that the temporal generalized quantifier *each meeting* (20) maps any temporal predicate J to the statement that J holds of each interval which is a meeting; the expression *after each meeting* should map a temporal predicate J to the statement that J holds after each interval which is a meeting. Therefore the preposition *after* should denote a function which takes a temporal generalized quantifier of the form $\lambda J.\phi$ and "injects" the temporal function **after** into the complement(s) of J in ϕ.

(22) after $\rightsquigarrow \lambda \mathcal{T}^{(it)t}.\lambda J.\mathcal{T}(\lambda i.J(\mathbf{after}_{\hat{\imath}}(i)))$

The preposition *after* uses the overall temporal context of evaluation $\hat{\imath}$ as the context argument of the temporal primitive **after**; this will be used in the account of temporal cascades in section 2.8.

The temporal PP *after each meeting* gets its meaning by straightforward application of the preposition *after* (22) to the temporal generalized quantifier *each meeting* (20). The result is a temporal generalized quantifier.

(23) after each meeting $\rightsquigarrow \lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow J(\mathbf{after}_{\hat{\imath}}(i))]$

The PP *after each meeting* modifies the sentence *Bill cried* (I assume for the moment that the PP attaches as an adjunct to the entire main clause, this will be revised in section 2.7). The temporal generalized quantifier (23) needs to apply to a temporal property; we form such a property by abstracting over the free temporal context variable $\hat{\imath}$ in the existentially closed meaning of the main clause (13b). This has the effect of subordinating the temporal context of the main clause to that of the temporal modifier.

(24) Bill cried after each meeting $\rightsquigarrow$
$\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow J(\mathbf{after}_{\hat{\imath}}(i))](\lambda\hat{\imath}.\exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{cry}(\mathbf{bill})(i')])$
$= \forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]$

Abstracting over the temporal context variable in order to allow temporal modification is essentially the same as Dowty's rule for combining a time adverbial with a sentence (Dowty 1982:35, rule S43). We can view this abstraction as part of the rule of temporal modification, or as an independent operation that necessarily precedes it; an independent application of an abstraction operation will be needed for the computation of aggregate readings in section 3.4.1. Shortly below we will also see that abstraction over the temporal context variable has to apply to types other than t (making it more general than Dowty's rule), and we will revise the abstraction rule accordingly in section 2.7.2, example (54).

2.4. TEMPORAL CLAUSES

Temporal clauses like *after Sue arrived* also denote temporal generalized quantifiers. Their meanings are derived in a similar way to temporal PPs, through application of the contextualization operation followed by a determiner meaning. The raw meaning of a clause like *Sue arrived* is a property of times (25), to which a temporal context variable is added by the contextualization operation (26) in a manner completely analogous to that of the clause *Bill cried* (11)–(12b).

(25) Sue arrived $\rightsquigarrow \lambda i.\mathbf{arrive}(\mathbf{sue})(i)$

(26) Sue arrived $\rightsquigarrow \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{arrive}(\mathbf{sue})(i)$

However, unlike a matrix clause whose temporal argument is existentially closed at this stage, a temporal clause needs to have a determiner applied to it in order to turn it into a temporal generalized quantifier. There is no overt determiner, so an implicit existential determiner meaning (27) is applied, followed by the preposition *after* (22).

(27) Implicit existential determiner: $\lambda I \lambda J.\exists i[I(i) \wedge J(i)]$

(28) Sue arrived $\rightsquigarrow \lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{arrive}(\mathbf{sue})(i) \wedge J(i)]$

(29) after Sue arrived $\rightsquigarrow \lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{arrive}(\mathbf{sue})(i) \wedge J(\mathbf{after}_{\hat{\imath}}(i))]$

There are two reasons not to subsume the determiner meaning under the semantics of *after*. The obvious reason is to keep the semantics of *after* with a clausal complement identical to that of *after* with an NP complement: *after* applies to NPs with determiners (that is to temporal generalized quantifiers), so its clausal complements should also denote temporal generalized quantifiers, and this requires the application of an independent determiner. Another reason to assume that the determiner is not part of the meaning of *after* is that certain operations may intervene between *after* and the determiner meaning—for example, a quantificational argument in the temporal clause should be allowed to take scope above the determiner in order to give it scope above the matrix clause; such constructions will be discussed in detail in section 3. The existential determiner is therefore an independent semantic operation, triggered by the temporal complementizer but applying below it.

The temporal generalized quantifier (29) combines with the meaning of the matrix clause and yields the correct results.

(30) Bill cried after Sue arrived $\rightsquigarrow$
$$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{arrive}(\mathbf{sue})(i) \wedge J(\mathbf{after}_{\hat{\imath}}(i))](\lambda \hat{\imath}\exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{cry}(\mathbf{bill})(i')])$$
$$= \exists i[i \subseteq \hat{\imath} \wedge \mathbf{arrive}(\mathbf{sue})(i) \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]$$

Sentence (30) is true if there exists an interval (within the overall frame) in which Sue arrived, followed by an interval at which Bill cried.

Looking at the representation (30), we can already see where our analysis is headed: the temporal clause in (30) takes semantic scope over the entire sentence, and this will be used in section 3 to explain how a nominal quantifier in a temporal clause can take scope above a quantifier in the matrix clause. Before we get there, we turn to two issues that were glossed over in the preceding discussion, namely tense and temporal prepositions (sections 2.5 and 2.6 respectively); the remainder of section 2 then continues to develop temporal generalized quantifier theory, which is the basis for the semantics that follows.

2.5. TENSE

An anonymous reviewer notes that if tense is taken to apply above the temporal modifier in (24), it will modify the context of the temporal PP rather than the time of the verb. This is undesirable, because such an analysis would predict that in a sentence like *Bill cried before the meeting* the meeting must be in the past, whereas the sentence can be uttered felicitously if the meeting is still going on. The conclusion from this example is that tense should apply below the temporal modifier, so that it modifies the verb itself.

I will demonstrate how this treatment of tense works by deriving again the meaning of *Bill cried after each meeting*, this time interpreting the tense morphology on the verb. Unlike temporal adverbs and PPs which modify a sentence's context of evaluation, tense should modify the event time directly. The reason is that adverbial modification identifies the context of the modified sentence with the event time(s) of the temporal modifier. In the sentence *Bill cried today*, the context of *Bill cried* is the event time of *today*; only the event time of Bill's crying should be in the past, not its context. We therefore spell out the meaning of the past tense morpheme as a modifier of temporal properties, type $(it)it$.

(31) PAST $\rightsquigarrow \lambda J.\lambda i[\mathbf{past}(i) \wedge J(i)]$

Past tense must apply before existential closure, when the event time is still accessible; its ordering with respect to contextualization is not crucial.

(32) Contextualized: Bill cried $\rightsquigarrow \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{past}(i) \wedge \mathbf{cry}(\mathbf{bill})(i)$

(33) Existentially closed: Bill cried $\rightsquigarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{past}(i) \wedge \mathbf{cry}(\mathbf{bill})(i)]$

The temporal PP *after each meeting* (23) works in the same fashion as in the previous section, applying to the temporal property formed by abstracting over the free temporal context variable $\hat{\imath}$ in the existentially closed tensed sentence *Bill cried* (33).

(34) Bill cried after each meeting $\rightsquigarrow$

$$\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow J(\mathbf{after}_{\hat{\imath}}(i))]$$
$$(\lambda \hat{\imath}.\exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{past}(i') \wedge \mathbf{cry}(\mathbf{bill})(i')])$$
$$= \forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow$$
$$\exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{past}(i') \wedge \mathbf{cry}(\mathbf{bill})(i')]]$$

The final representation has the desired result: each event-time i' of Bill crying is past, but tense does not directly modify the contexts of the crying or the meeting times. Of course, the meetings in (34) must also be in the past if the sentence is true; this is an entailment that comes from the condition that each meeting precedes a past crying time.

The above representation also shows us how tense can restrict the overall context of evaluation. In an attempt to explain why in a sentence like *John called every Monday* the domain of quantification appears to be restricted to past Mondays, von Stechow (2002:759) suggests that tense applies above the temporal modifier PP. This suggestion is subject to the criticism noted at the beginning of this section—the sentence can be uttered felicitously on a Monday and include the day of utterance in the domain of quantification. It appears that von Stechow himself is not too happy with his solution, and he hints that a better approach would follow a proposal he cites from class notes by Irene Heim: tense should modify the verb, and restrict the domain of quantification by means of a presupposition. The analysis sketched above comes close to such a characterization: the domain of quantification over Mondays is restricted by the overall temporal context of evaluation, and any choice of such context that includes a future Monday will make the sentence false (it comes out as false rather than leading to a presupposition failure because the semantic import of the past tense morpheme, $\mathbf{past}(i')$, is entered to the representation as part of the assertion).

This much said about tense, I will ignore it in all subsequent discussion. Tense is a very intricate topic which cannot receive an adequate treatment within the scope of this paper; at the same time, the complications raised by tense are quite orthogonal to the questions of quantifier scope across clauses that this paper set out to investigate. I therefore choose to leave tense out of the discussion, and I will continue to treat all the examples in the remainder of this paper as if they are tenseless.

2.6. Remarks on temporal prepositions

2.6.1. *The type of temporal primitives*

The preposition meanings introduced in section 2.3 are based on temporal primitives of type iii, following Pratt and Francez (2001) and Francez and Steedman (to appear); this stands in contrast to von Stechow (2002), who views temporal prepositions as relations of type iit. One difference between the two analyses is that the iii-type analysis includes a slot for the context of evaluation; this context is needed for the account of temporal cascades in section 2.8. A comparable account of prepositions as relations would therefore involve a relation of type $iiit$, between two event times and a third context time.

The functional and relational accounts of temporal primitives are equivalent, and each primitive can be expressed in terms of the other.

(35) Let $\lambda i \lambda j.\mathbf{after}_i(j)$ be the temporal primitive (21), a function of type iii that maps an interval j and a context i to the interval spanning from the end of j to the end of i, if $j \subseteq i$.

Let $\lambda i \lambda j \lambda j'.\text{AFTER}(i, j, j')$ be a three-part relation of type $iiit$ which is true if j' follows j within the context i. Then:

a. $\text{AFTER}(i, j, j')$ if and only if $j' \subseteq \mathbf{after}_i(j)$.

b. $\mathbf{after}_i(j) = \mathbf{max}(\lambda j'.\text{AFTER}(i, j, j'))$, where $\mathbf{max}(J)$ is the maximal interval i such that $J(i)$ is true, if such an interval exists.

The reason I prefer the iii-type notation is as follows. We have seen above in section 2.3 that a formula like the one in (35a) belongs below the scope of the quantifier introduced by a temporal NP like *every meeting*. Syntactically, however, the quantified NP is a complement of the preposition *after*. The problem is addressed by von Stechow (2002) through a syntactic movement rule that brings the temporal NP above the preposition at Logical Form, but a theory that is faithful to surface constituent structure requires a semantic mechanism to bring the temporal relation below the scope of the quantifier. This is achieved in this paper through a higher-order translation of temporal prepositions, which builds on lower-type temporal primitives (essentially the same mechanism is employed by Pratt and Francez 2001 and Francez and Steedman to appear). Such a mechanism is easiest to write if we express the temporal primitive as a function which yields an interval of type i; expressing the primitive as a relation would make the translations more difficult to read.

Not all temporal primitives can be equally formulated as relations and functions. Whatever functional meaning we give to the primitive **throughout**, the representation $j' \subseteq \mathbf{throughout}_i(j)$ does not express the appropriate relation, namely that the interval j' lasts throughout the duration of j (thanks to Ariel Cohen for pointing this out). The problem is with the temporal inclusion relation $\subseteq$, introduced by the contextualization operation. There are two solutions to this problem, both based on the observation that the preposition *throughout* may only modify predicates of certain aspectual classes. One solution is offered by Pratt and Francez (1997): *throughout* is subjected to a lexical restriction which allows it to only apply to universally quantified temporal predicates; the other solution follows the suggestion of von Stechow (2002) to replace the inclusion relation $\subseteq$ by modeling various verb aspects with distinct contextualization operations. We do not need to go deeper into either of the solutions in this paper, because the issue does not seem to affect quantifier scope.

2.6.2. *Refinements to preposition meanings*

The semantic primitive **after** is not fine-grained enough. For example, the formula derived in (24) for *Bill cried after each meeting* is satisfied if Bill cried once, after the last meeting. One could argue that this is correct on a very literal interpretation of the sentence, but the sentence normally implies a tighter connection between the meeting times and the crying times. One way to capture this is through additional parameterization of the primitive **after**. Pratt and Francez (2001:199) note that the word *before* often has a meaning of "just before" or "a short time before"; the same holds for *after*. Such a meaning can be expressed in our semantics by a primitive function $\lambda i \lambda \epsilon \lambda j.\mathbf{after}_{i,\epsilon}(j)$, which maps a context i, a contextually determined length of time ϵ, and an interval j to the interval that begins at the end of j, has a maximal length ϵ, and extends maximally to the end of i (a preposition meaning that takes a length argument is needed anyway for PPs that include an explicit degree expression, e.g. *at most two minutes after each meeting*). But a single, fixed length ϵ may not be sufficient for *Bill cried after each meeting*, because the sentence normally implies that for each meeting, Bill cried after it and before the next meeting. We should therefore take ϵ as a function whose range is lengths of time and whose domain includes various contextual factors, among them the event time j (or even the event itself). As noted by Kamp and Reyle (1993:628), it is very difficult to give a precise characterization of all the factors that constrain the distance between the event times of the modified clause and the temporal modifier; I will not attempt such a characterization here.

An alternative to the parameterization of the function **after** is to enforce a connection between the times of the modifier and the modified clause through a matching mechanism along the lines of Rothstein (1995). Rothstein notices that sentences like *every time John rings the bell, Mary opens the door* have a "matching effect", whereby each ringing event must be matched by a distinct opening event. I am not clear as to whether such an effect exists in sentences with temporal prepositions. Take the sentence *after each bell rings, Mary* *opens the door*, or the sentence *after each chime, Mary opens the door*: if two bells ring or chime simultaneously, is one door opening sufficient to make the sentence true? I am not sure what the answer is. If there is a matching effect in these cases, it should be possible to add events to our semantics and incorporate a matching function like that of Rothstein (1995). But even if a matching mechanism is applied, it will still not enforce the temporal interleaving of crying times and meeting times in *Bill cried after each meeting*, so inserting contextual parameters to the function **after** seems inevitable.

Both the question of temporal primitive parameterization and the question of a matching effect are orthogonal to the problem of quantifier interaction across temporal adjunct clauses. We will therefore continue with the same meanings for primitives we defined in section 2.3.

2.6.3. *Prepositions of temporal identity*

Temporal prepositions other than *after* have translations similar to (22), with the appropriate temporal function replacing **after**. But temporal prepositions which denote identity of time, such as *during*, *on* and *in*, have a curious property: when such a preposition takes an NP complement, the meaning of the resulting PP temporal generalized quantifier turns out to be identical to the original meaning of the complement NP temporal generalized quantifier. This follows from two assumptions about natural language NP meanings: one is that temporal determiners only apply to contextualized NPs, and the other is that natural language determiners are conservative (Keenan and Stavi 1986). Here is the proof. We start with the definitions of the temporal primitive **during** and the preposition *during*.

(36) $\mathbf{during}_i(j)$ is the interval j itself, if $j \subseteq i$; undefined otherwise.

(37) The preposition *during* translates as $\lambda\mathcal{T}^{(it)t}.\lambda J.\mathcal{T}(\lambda i.J(\mathbf{during}_{\hat{\imath}}(i)))$.

Let *CN* be a temporal common noun with meaning $\lambda i.\mathcal{N}(i)$ of type it, and let *Det* be a conservative temporal determiner with meaning $\lambda I\lambda J.\mathcal{D}(I)(J)$ of type $(it)(it)t$. Conservativity is defined as follows.

(38) $\mathcal{D}(I)(J)$ if and only if $\mathcal{D}(I)(\lambda i.I(i) \wedge J(i))$

A quantificational NP *Det CN* is formed by applying the determiner meaning $\mathcal{D}$ to the *contextualized* common noun meaning $\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i)$.

(39) $\lambda J.\mathcal{D}(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i))(J)$

The preposition *during* applies to the above to give the PP *during Det CN*.

(40) $\lambda J.\mathcal{D}(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i))(\lambda i.J(\mathbf{during}_{\hat{\imath}}(i)))$

By conservativity, this is equivalent to the following.

(41) $\lambda J.\mathcal{D}(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i))(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i) \wedge J(\mathbf{during}_{\hat{\imath}}(i)))$

We can now simplify the expression in the second argument of $\mathcal{D}$: by the definition in (36), the expression $\mathbf{during}_{\hat{\imath}}(i)$ is equivalent to i if $i \subseteq \hat{\imath}$. Since $\mathbf{during}_{\hat{\imath}}(i)$ in the above expression is part of an expression that's conjoined with $i \subseteq \hat{\imath}$, we can safely rewrite it as i.

(42) $\lambda J.\mathcal{D}(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i))(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i) \wedge J(i))$

Applying the conservativity hypothesis again, we arrive at a representation that is equivalent to the meaning of the NP *Det CN* (39).

(43) $\lambda J.\mathcal{D}(\lambda i.i \subseteq \hat{\imath} \wedge \mathcal{N}(i))(\lambda i.J(i))$

This concludes the proof that when the preposition *during* applies to a temporal generalized quantifier formed from a conservative determiner and a contextualized temporal property, the result is identical to applying the identity function on temporal generalized quantifiers ($\lambda\mathcal{T}.\mathcal{T}$). By hypothesis, this is the case with all natural language temporal generalized quantifiers. From now on, in order to keep things simple, I will treat *during* and similar prepositions as if they do indeed denote identity. It is important to remember that this is not an arbitrary stipulation, but rather a result derived from the meanings of primitive temporal functions.

Of course, the preposition *during* is not redundant: it serves to indicate that the following NP is to be interpreted temporally. In the theory developed here, the semantic type of common nouns depends on their syntactic position: *during* forces the head noun of its complement to be of type it rather than et. In a theory where common nouns like *meeting* invariably denote predicates of events (Pratt and Francez 2001, Francez and Steedman to appear), the preposition *during* (along with all other temporal prepositions) is a type-changer, transforming event generalized quantifiers into temporal generalized quantifiers.

2.7. THE SCOPE OF TEMPORAL GENERALIZED QUANTIFIERS

Temporal generalized quantifiers can interact scopally with a quantificational argument of the verb. The following sentence displays a classical scope ambiguity.

(44) $\left\{\begin{array}{l}\text{Exactly three executives}\\ \text{Few executives}\\ \text{Some executive}\end{array}\right\}$ cried during each meeting.

The two scoped readings are independent of one another. A wide scope reading of *exactly three executives* states that exactly three executives are such that they cried during each meeting (though at some or all of the meetings there may have been additional executives who cried); a narrow scope reading of *exactly three executives* states that at each meeting, the number of executives who cried was exactly three (but not necessarily the same executives cried at all meetings). In order to account for the scoped readings we need to resolve some type mismatches that arise in the course of semantic derivation, as well as generalize the temporal abstraction rule to apply to types other than t, as promised at the end of section 2.3.

A natural way to think of the two scoped readings is to assume that the nominal and temporal generalized quantifiers attach to the verb in different orders, as demonstrated by the following structures.

(45) a. [[Some executive cried] during each meeting].

b. Some executive [[cried] during each meeting].

There is evidence that (45a) is *not* the correct syntactic structure, and that both scope readings obtain from the syntactic structure (45b). For example, VP ellipsis in the following sentence suggests that the temporal PP is adjunct to VP as in (45b), yet a wide scope reading of the temporal PP is still available.

(46) A vase broke during each meeting and a bottle did too.

Furthermore, the ability of the nominal and temporal generalized quantifiers to have two scope relations cannot be attributed to their surface positions on two sides of the verb in (44), since the scope ambiguity present in (44) also shows up when the quantificational argument is a direct object (a narrow scope reading for the temporal quantifier is salient when the nominal determiner has a rising pitch accent; cf. Büring 1997a, 1997b, 1999).

(47) $$\text{Mary scolded} \left\{ \begin{array}{l} \text{Exactly three executives} \\ \text{Few executives} \\ \text{Some executive} \end{array} \right\} \text{during each meeting.}$$

However, this paper concentrates on the semantics of temporal expressions, so I will put aside the question of precise syntactic representation. Various mechanisms can be used to account for scope, among them Quantifying-in (Montague 1973), Quantifier Storage (Cooper 1983) and Quantifier Raising (May 1985); to my knowledge, the data discussed in this paper do not present new arguments for choosing among them. All the scope mechanisms allow two different orders of application of the nominal and temporal generalized quantifiers to the verb; the same is true of the structures (45a) and (45b), and this is sufficient for our purpose.

2.7.1. *Wide scope temporal generalized quantifiers*

We start with the wide scope reading for the temporal generalized quantifier in the sentence *some executive cried during each meeting*. The meaning of the unmodified clause, *some executive cried*, is the result of applying the subject as well as contextualization and existential closure to the verb *cry*, which is a function of type eit.

(10) cry $\rightsquigarrow \lambda x \lambda i.\mathbf{cry}(x)(i)$

In section 2.2 we saw how contextualization and existential closure apply to the entire sentence; contextualization and existential closure can also apply to the verb directly by using a mechanism that gives the subject scope above these operations, for instance Quantifying-in, Quantifier Storage or Quantifier Raising (thanks to Idan Landau for pointing out the importance of using a scope mechanism for this purpose). In the sentence *some executive cried*, the relative scope of the subject and existential closure doesn't matter because they both contribute existential quantifiers. However, it is instructive to show how contextualization and existential closure apply to the verb, because this will be needed in section 2.7.2.

The contextualization operation (12a) is a function of type $(it)it$, and is thus of the wrong type to combine with the verb via functional application; it can however combine via functional composition.

(48) Functional composition: $f^{\sigma\tau} \circ g^{\rho\sigma} =_{\mathrm{df}} \lambda r^{\rho}.f(g(r))$
[ρ, σ, τ are variables over types]

(49) cry $\rightsquigarrow \lambda I \lambda i.i \subseteq \hat{\imath} \wedge I(i) \circ \lambda x \lambda i.\mathbf{cry}(x)(i)$
$= \lambda x.[\lambda I \lambda i.i \subseteq \hat{\imath} \wedge I(i)]([\lambda x \lambda i.\mathbf{cry}(x)(i)](x))$
$= \lambda x \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)$

The existentially closed meaning of the verb *cry* is likewise arrived at through functional composition of the existential closure operation (13a) with the contextualized meaning of the verb.

(50) cry $\rightsquigarrow \lambda I.\exists i[I(i)] \circ \lambda x \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)$
$= \lambda x.[\lambda I.\exists i[I(i)]]([\lambda x \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)](x))$
$= \lambda x.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)]$

The subject *some executive* is a familiar (nominal) generalized quantifier; it applies to the VP meaning to give the meaning of the sentence *some executive cried*, with a free temporal context variable.

(51) some executive $\rightsquigarrow \lambda P.\exists x[\mathbf{exec}(x) \wedge P(x)]$

(52) some executive cried $\rightsquigarrow$
$\lambda P.\exists x[\mathbf{exec}(x) \wedge P(x)](\lambda x.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)])$
$= \exists x[\mathbf{exec}(x) \wedge \exists i[i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)]]$

Finally, the temporal PP applies. Recall the discussion in section 2.6.3, which established that the meaning of *during each meeting* is identical to that of *each meeting* (20). This is a temporal generalized quantifier, and it applies to the $\lambda\hat{\imath}$-abstract over the meaning of *some executive cried.*

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(53) some executive cried during each meeting $\rightsquigarrow$

$$\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \textbf{meeting}(i)) \rightarrow J(i)]$$
$$(\lambda\hat{\imath}.\exists x[\textbf{exec}(x) \wedge \exists i'[i' \subseteq \hat{\imath} \wedge \textbf{cry}(x)(i')]])$$
$$= \forall i[(i \subseteq \hat{\imath} \wedge \textbf{meeting}(i)) \rightarrow \exists x[\textbf{exec}(x) \wedge \exists i'[i' \subseteq i \wedge \textbf{cry}(x)(i')]]]$$

The resulting meaning is that for each meeting there is an executive who cried during that meeting. Executives may vary with meetings, which is precisely the reading we want.

2.7.2. *Narrow scope temporal generalized quantifiers*

In order to get a narrow scope reading for the temporal generalized quantifier in the sentence *some executive cried during each meeting*, the temporal PP has to apply to the verb before the subject does. As in the previous cases of temporal modification, the temporal generalized quantifier meaning of the modifier has to combine with an abstract over the temporal context variable of the existentially closed meaning of the verb (50). Since the latter is of a type higher than t, simple prefixation of $\lambda\hat{\imath}$ to the verb meaning will not work. Rather, the lambda abstract over the temporal context variable is added to the verb meaning as the last lambda operator.

(54) A temporal modifier denoting a temporal generalized quantifier $\mathcal{T}$ of type $(it)t$ combines with a constituent with a denotation $\lambda s_1 \ldots \lambda s_n.\phi$ of type $\sigma_1 \ldots \sigma_n t$ for some $n \geq 0$ via functional application or composition (whichever is appropriate) of $\mathcal{T}$ to the meaning $\lambda s_1 \ldots \lambda s_n \lambda\hat{\imath}.\phi$ (the string of lambdas may be empty).

When the modified constituent is of type t, the rule results in prefixation of $\lambda\hat{\imath}$ as we have seen so far. When the rule is applied to a predicate of type et, the abstractor $\lambda\hat{\imath}$ skips over the initial λx; this can be thought of as functional composition of the abstraction operation itself (thanks to Fred Landman for this observation).

The meaning of the VP *cried during each meeting* is derived through functional composition of the temporal generalized quantifier with the lambda abstract over the temporal context variable of the verb meaning (55); the VP then combines with the subject meaning (51) to give the meaning of the complete sentence (56).

(55) cried during each meeting $\rightsquigarrow$

$$\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \textbf{meeting}(i)) \rightarrow J(i)] \circ \lambda x\lambda\hat{\imath}.\exists i'[i' \subseteq \hat{\imath} \wedge \textbf{cry}(x)(i')]$$
$$= \lambda x.[\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \textbf{meeting}(i)) \rightarrow J(i)]]$$
$$([\lambda x\lambda\hat{\imath}.\exists i'[i' \subseteq \hat{\imath} \wedge \textbf{cry}(x)(i')]](x))$$
$$= \lambda x.\forall i[(i \subseteq \hat{\imath} \wedge \textbf{meeting}(i)) \rightarrow \exists i'[i' \subseteq i \wedge \textbf{cry}(x)(i')]]$$

(56) some executive cried during each meeting $\rightsquigarrow$
$$\lambda P.\exists x[\mathbf{exec}(x) \wedge P(x)]$$
$$(\lambda x.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{cry}(x)(i')]])$$
$$= \exists x[\mathbf{exec}(x) \wedge \forall i[(i \subseteq \hat{\imath} \wedge \mathbf{meeting}(i)) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{cry}(x)(i')]]]$$

This derivation entails the existence of one particular executive who cried at each meeting, which is the desired narrow-scope reading of the temporal generalized quantifier.

2.8. Temporal cascades

A temporally modified sentence can be modified again, resulting in what Pratt and Francez (2001) call temporal cascades. Take for example the sentence *Bill cried after each meeting on Tuesday*, where *Tuesday* is taken to refer to a particular day (e.g. Tuesday, March 11, 2003): the sentence is true if the sentence *Bill cried after each meeting* is true when evaluated on Tuesday. The word *Tuesday* will be translated as the constant **tues** of type it (a property of time intervals). Constituents like *every Tuesday* or *few Tuesdays* show that the function **tues** is true of all intervals which are Tuesdays, but when translating bare *Tuesday* the function is true of only one particular interval which is determined from context; how it gets chosen is a complicated matter which will not concern us here (for discussion see Kamp and Reyle 1993:614ff).

Like other temporal predicates, *Tuesday* is interpreted in context (57); an implicit existential determiner meaning (27) turns the contextualized temporal property into a temporal generalized quantifier (58).

(57) Tuesday $\rightsquigarrow \lambda i.i \subseteq \hat{\imath} \wedge \mathbf{tues}(i)$

(58) Tuesday $\rightsquigarrow \lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge J(i)]$

The preposition *on*, like its counterpart *during*, does not change the meaning of its complement (cf. section 2.6.3), and the resulting temporal generalized quantifier combines with the $\lambda\hat{\imath}$-abstract over the meaning of the sentence *Bill cried after each meeting* (24).

(59) on Tuesday $\rightsquigarrow \lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge J(i)]$

(60) Bill cried after each meeting on Tuesday $\rightsquigarrow$
$$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge J(i)]$$
$$(\lambda\hat{\imath}\forall i'[(i' \subseteq \hat{\imath} \wedge \mathbf{meeting}(i')) \rightarrow \exists i''[i'' \subseteq \mathbf{after}_{\hat{\imath}}(i') \wedge \mathbf{cry}(\mathbf{bill})(i'')]])$$
$$= \exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge$$
$$\forall i'[(i' \subseteq i \wedge \mathbf{meeting}(i')) \rightarrow \exists i''[i'' \subseteq \mathbf{after}_{i}(i') \wedge \mathbf{cry}(\mathbf{bill})(i'')]]]$$

This is the correct meaning of the sentence—there is some interval which is Tuesday, and each meeting during this interval was followed by an interval in which Bill cried.

2.9. TEMPORAL MODIFICATION OF NOUNS

The sentence *Bill cried after each meeting on a Tuesday* has a reading which is true if there were several Tuesday meetings and Bill cried after each of them; the crying intervals themselves do not have to be on Tuesdays. This reading arises when the PP *on a Tuesday* modifies the noun *meeting* rather than the verb *cried* (Pratt and Francez 2001, Francez and Steedman to appear).

(61) Bill cried after [each [meeting on a Tuesday]]

The discussion of the semantics of this structure will lead to a general constraint on semantic derivations, which will be important in ruling out certain undesired readings in section 3.

We start with the modified common noun in (61). A $\lambda\hat{\imath}$ operator is added to the contextualized meaning of the noun *meeting* (18) according to the rule (54), and this composes with the temporal generalized quantifier *on a Tuesday*, yielding the representation in (62).

(62) meeting on a Tuesday $\rightsquigarrow$

$$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge J(i)] \circ \lambda i'\lambda\hat{\imath}.i' \subseteq \hat{\imath} \wedge \mathbf{meeting}(i')$$
$$= \lambda i'.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge i' \subseteq i \wedge \mathbf{meeting}(i')]$$

The temporal property (62) is true of an interval if it is both a meeting and on a Tuesday. The temporal determiner *each* applies to the above representation creating a temporal generalized quantifier (63); this is modified by the preposition *after*, and the resulting temporal generalized quantifier (64) applies to the sentence *Bill cried* (65).

(63) each meeting on a Tuesday $\rightsquigarrow$

$$\lambda J.\forall i'[\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge i' \subseteq i \wedge \mathbf{meeting}(i')] \rightarrow J(i')]$$

(64) after each meeting on a Tuesday $\rightsquigarrow$

$$\lambda J.\forall i'[\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge i' \subseteq i \wedge \mathbf{meeting}(i')] \rightarrow J(\mathbf{after}_{\hat{\imath}}(i'))]$$

(65) Bill cried after each meeting on a Tuesday $\rightsquigarrow$

$$\forall i'[\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge i' \subseteq i \wedge \mathbf{meeting}(i')] \rightarrow$$
$$\exists i''[i'' \subseteq \mathbf{after}_{\hat{\imath}}(i') \wedge \mathbf{cry}(\mathbf{bill})(i'')]]$$

The final translation is indeed the desired reading: each interval which is a meeting on a Tuesday is followed by an interval of Bill crying. The contextual parameter of **after** is the temporal context variable $\hat{\imath}$ which stands for the overall context, so the crying intervals are not necessarily on any Tuesday.

Adjunction of other temporal modifiers to common nouns is problematic. The following examples show what happens when the common noun *meeting* is modified by the PPs *on each Tuesday* and *on no Tuesday*.

(66) meeting on each Tuesday $\rightsquigarrow$
$$\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{tues}(i)) \rightarrow J(i)] \circ \lambda i'\lambda\hat{\imath}.i' \subseteq \hat{\imath} \wedge \mathbf{meeting}(i')$$
$$= \lambda i'.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{tues}(i)) \rightarrow i' \subseteq i \wedge \mathbf{meeting}(i')]$$

(67) meeting on no Tuesday $\rightsquigarrow$
$$\lambda J.\neg\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge J(i)] \circ \lambda i'\lambda\hat{\imath}.i' \subseteq \hat{\imath} \wedge \mathbf{meeting}(i')$$
$$= \lambda i'.\neg\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge i' \subseteq i \wedge \mathbf{meeting}(i')]$$

The temporal property (66) is true of an interval if it is a meeting and is included in each Tuesday in the context; the temporal property (67) is even more bizarre—it is true of any interval which is not a meeting on a Tuesday! Both properties lead to incorrect truth conditions when they combine with a determiner and a temporal preposition to modify a sentence.

(68) Bill cried after a meeting on each Tuesday $\rightsquigarrow$
$$\exists i'[\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{tues}(i)) \rightarrow i' \subseteq i \wedge \mathbf{meeting}(i')] \wedge$$
$$\exists i''[i'' \subseteq \mathbf{after}_{\hat{\imath}}(i') \wedge \mathbf{cry}(\mathbf{bill})(i'')]]$$

(69) Bill cried after a meeting on no Tuesday $\rightsquigarrow$
$$\exists i'[\neg\exists i[i \subseteq \hat{\imath} \wedge \mathbf{tues}(i) \wedge i' \subseteq i \wedge \mathbf{meeting}(i')] \wedge$$
$$\exists i''[i'' \subseteq \mathbf{after}_{\hat{\imath}}(i') \wedge \mathbf{cry}(\mathbf{bill})(i'')]]$$

The formula in (68) cannot be true if the context $\hat{\imath}$ includes two or more non-overlapping Tuesdays, which may or may not be desirable. If the context contains just one Tuesday the formula can be true, and if there are no Tuesdays in the context then the condition (66) is trivially satisfied and the sentence is true as long as Bill cried, even if there are no meetings at all. This is obviously incorrect. As for (69), it is true if Bill cried after an interval which is either not a meeting, or not on a Tuesday, or not in the context of evaluation. This is sheer nonsense.

It is debatable whether the constituents (66) and (67), and consequently the sentences (68) and (69), have any meaning at at all. I will therefore not try to find another way of assigning meanings to these structures, but rather be content with blocking the meanings we presently get. The fault with the above representations is that the translation of *meeting* together with its context variable are separated from their determiner by the determiner of the noun *Tuesday*; an intervening determiner also exists in (62)–(65), but since this determiner is existential it causes no ill effects. I will therefore block the unwanted representations by stipulating the following constraint on semantic derivations.

(70) A universal or negative generalized quantifier may not apply to a contextualized temporal property before a determiner does.

This stipulation is not pretty, and begs for further investigation. It would be nicer if we could say that the restriction (70) applies to all modifiers and rule out such structures in the syntax, but this would require an alternative means to get the meaning (65). I therefore leave the stipulation as it is.

We should also note that temporal modifiers adjoin not only to common nouns but also to full NPs.

(71) Bill cried after [[a meeting] on each Tuesday]

In this structure the PP *on each Tuesday* takes scope above the determiner of *a meeting*, in a similar fashion to what we see in a sentence like *Two volunteers from each class decorated the room*. The resulting reading is that on each Tuesday there is a (separate) meeting, after which Bill cried, with the crying not necessarily on Tuesday. This comes through straightforward application of our semantics; I will not give the full derivation here, since structures like this will not play a role in our subsequent discussion.

2.10. SUMMARY

The basic theory of temporal modification involves the following operations.

Contextualization (12a) applies to all temporal nouns, and all verbs.

Existential closure (13a) applies at the top of the clause to all temporally modified clauses (as well as other clauses that are not temporal modifiers). It always applies to contextualized properties.

An implicit temporal determiner (27) applies at the top of the clause to all temporal modifier clauses, and to temporal common nouns that lack an explicit determiner. It always applies to contextualized properties.

Temporal modification (54) involves abstraction over the temporal context variable of the temporally modified constituent.

Quantificational arguments and temporal modifiers (nominal and temporal generalized quantifiers) may take scope over the existential closure operation (13a); this has the effect of applying existential closure at a lower level, close to the verb. However, a universal or negative generalized quantifier may not intervene between a contextualized temporal property and its determiner (70).

3. Temporal clauses and quantifier scope

A temporal clause may have a quantificational subject, as in sentence (72), repeated from section 1.

(72) A secretary cried after each executive resigned.

Under one reading of the sentence (possibly the most salient one), the sentence is true if each resignation is followed by the crying of a possibly different secretary. The subject of the temporal clause takes scope above the subject of the matrix clause, in what appears to be a violation of a locality constraint: quantifiers do not normally take scope outside of adjunct clauses (cf. Huang 1982). This is one of a family of readings which I will call *dependent-time* readings, where the times at which the matrix clause is evaluated depend on quantifiers within the temporal clause. I will show that dependent-time readings do not violate the adjunct island constraint: they arise from local scope relations within the adjunct clause, where the quantificational argument takes scope above the implicit temporal determiner. (Issues pertaining to the relative scope of temporal determiners and quantificational arguments were noted in Pratt and Francez 1997:9–11, but not applied to temporal clauses.)

Dependent-time readings will be discussed in section 3.2 below, following the discussion of the simpler single-time readings in section 3.1. Section 3.3 looks at restrictions on the readings produced in the preceding sections, and section 3.4 explores the complicated cases of temporal clauses that have internal temporal modifiers.

3.1. Single-time readings

The single-time reading of (72) entails that all the executives resigned at the same time. This reading obtains when contextualization and the implicit temporal determiner apply to the entire temporal clause, above its subject. Before contextualization, the quantificational subject *each executive* has to apply to the verb *resigned*. This results in a type mismatch, because the verb (73) is of type eit while the subject (74) expects an argument of type et.

(73) resigned $\rightsquigarrow \lambda x \lambda i.\mathbf{resign}(x)(i)$

(74) each executive $\rightsquigarrow \lambda P.\forall x[\mathbf{exec}(x) \rightarrow P(x)]$

Pratt and Francez (2001) solve the mismatch through an operation of "pseudo-application", which makes the temporal lambda term of the verb invisible to the subject. I will use a more traditional approach of type shifting. We can either shift the type of the verb according to the scheme in (75) or shift the type of the subject according to the scheme in (76).

(75) Shifting the type of the verb: A relation R of type $\sigma\tau t$ applies to a generalized quantifier of type $(\sigma t)t$ by raising to type $((\sigma t)t)\tau t$:

$$R^{\sigma\tau t} \mapsto \lambda\mathcal{T}^{(\sigma t)t}\lambda u^{\tau}.\mathcal{T}(\lambda s^{\sigma}.R(s)(u))$$

(76) Shifting the type of the subject: A generalized quantifier $\mathcal{T}$ of type $(\sigma t)t$ applies to a relation of type $\sigma\tau t$ by raising to type $(\sigma\tau t)\tau t$:

$$\mathcal{T}^{(\sigma t)t} \mapsto \lambda R^{\sigma\tau t}\lambda u^{\tau}.\mathcal{T}(\lambda s^{\sigma}.R(s)(u))$$

These type-shifting schemes are nothing more than temporal versions of the ones needed in extensional, non-temporal semantics for combining a transitive verb of type *eet* with a quantificational direct object of type $(et)t$, allowing the object generalized quantifier to skip over subject slot of the verb. Both schemes are used in the literature for verb-object constructions: the standard approach to transitive verbs in Montague Grammar is that they accommodate generalized quantifier objects (Montague 1973), and such meanings are considered by Partee and Rooth (1983) to be the result of a type-shifting scheme like (75); a raised version of the generalized quantifier, corresponding to the scheme (76), is proposed in Steedman (2003).

Whichever type-shifting scheme we choose, the combination of the subject and the verb results in the following temporal property as the raw sentence meaning.

(77) each executive resigned $\rightsquigarrow \lambda i.\forall x[\mathbf{exec}(x) \rightarrow \mathbf{resign}(x)(i)]$

Contextualization (12a) and a determiner meaning (27) turn the above meaning into a temporal generalized quantifier (78), and are followed by the application of the preposition *after*.

(78) each executive resigned $\rightsquigarrow$
$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{exec}(x) \rightarrow \mathbf{resign}(x)(i)] \wedge J(i)]$

(79) after each executive resigned $\rightsquigarrow$
$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{exec}(x) \rightarrow \mathbf{resign}(x)(i)] \wedge J(\mathbf{after}_{\hat{\imath}}(i))]$

Finally, the temporal clause applies to the $\lambda\hat{\imath}$-abstract over the matrix clause, whose meaning is derived by applying the generalized quantifier *a secretary* to the contextualized and existentially closed meaning of *cry* (50).

(80) a secretary cried $\rightsquigarrow \exists x[\mathbf{secretary}(x) \wedge \exists i[i \subseteq \hat{\imath} \wedge \mathbf{cry}(x)(i)]]$

(81) a secretary cried after each executive resigned $\rightsquigarrow$
$$\begin{aligned}&\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{exec}(x) \rightarrow \mathbf{resign}(x)(i)] \wedge J(\mathbf{after}_{\hat{\imath}}(i))]\\ &\quad(\lambda\hat{\imath}.\exists y[\mathbf{secretary}(y) \wedge \exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{cry}(y)(i')]])\\ &= \exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{exec}(x) \rightarrow \mathbf{resign}(x)(i)] \wedge\\ &\quad\exists y[\mathbf{secretary}(y) \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(y)(i')]]]\end{aligned}$$

The result is indeed a single-time reading—there is a time interval at which all the executives resigned, and a secretary cried after that.

3.2. Dependent-time readings

If the implicit existential determiner applies to the verb of (72) before the subject does, we get a reading where resignation times vary with the resigning executives. Contextualization (12a) and a determiner meaning (27) can apply to the the raw verb by using a scope mechanism on the subject, as discussed in section 2.7.1.

(82) resigned $\rightsquigarrow \lambda x \lambda J.\exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge J(i)]$

The quantificational subject applies using one of the type-shifting schemes (75) or (76); the resulting temporal generalized quantifier is modified by the preposition *after*.

(83) each executive resigned $\rightsquigarrow$
$\lambda J.\forall x[\mathbf{exec}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge J(i)]]$

(84) after each executive resigned $\rightsquigarrow$
$\lambda J.\forall x[\mathbf{exec}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge J(\mathbf{after}_{\hat{\imath}}(i))]]$

At this point we can already see how the quantificational relations will end up. The universal quantifier contributed by the subject NP outscopes the temporal existential determiner; since the temporal property variable J lies within the scope of the temporal existential determiner, it also lies within the scope of the subject. The variable J will get replaced with the meaning of the matrix clause, so the matrix clause itself will fall under the scope of the subject of the temporal clause.

The temporal clause can take scope over the entire main clause (section 2.7.1). In this case the temporal generalized quantifier (84) applies to the $\lambda\hat{\imath}$-abstract over the matrix clause meaning (80).

(85) a secretary cried after each executive resigned $\rightsquigarrow$
$\lambda J.\forall x[\mathbf{exec}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge J(\mathbf{after}_{\hat{\imath}}(i))]]$
$(\lambda\hat{\imath}.\exists y[\mathbf{secretary}(y) \wedge \exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{cry}(y)(i')]])$
$= \forall x[\mathbf{exec}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge$
$\exists y[\mathbf{secretary}(y) \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(y)(i')]]]]$

We get a representation of the desired meaning—each executive resigned, and following that resignation a secretary cried; the secretaries may vary with the executives. The end result is that the subject of the temporal adjunct clause has scope over the subject of the main clause, but this is achieved through local operations: within the temporal clause, the subject takes scope over the temporal determiner; additionally, the entire temporal clause takes scope over the matrix subject. Thus, the representation (85) is not in violation of locality constraints.

The temporal clause may also modify the matrix predicate rather than the whole matrix clause. In this case the matrix subject takes scope above the temporal clause (section 2.7.2).

(86) a secretary cried after each executive resigned $\rightsquigarrow$
$= \exists y[\mathbf{secretary}(y) \wedge \forall x[\mathbf{exec}(x) \rightarrow$
$\exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(y)(i')]]]]$

This reading entails that there was one secretary who cried, but for each executive this secretary cried at a different time, namely after the executive's resignation. Readings (85) and (86) are both dependent-time readings, because the times at which the matrix predicate is evaluated depend on the subject of the temporal clause.

Arnim von Stechow has told me that dependent-time readings are not possible in German, and this judgment has been confirmed by other speakers. In terms of our theory, this means that German does not allow a quantificational argument to take scope over the temporal determiner. Martina Wiltschko has noted an interesting property in this regard: the German complementizer *nachdem* 'after' is composed of the morphemes *nach* 'after' (the preposition) and *dem* 'the'; it may be, then, that the temporal determiner is not implicit in German, but morphologically realized on the complementizer. Morphology cannot be the whole story, because the German complementizer *bevor* 'before' does not have a morphologically identifiable determiner; but it too is distinct from the preposition *vor* 'before'. Recall from section 2.4 that an important motivation in keeping the temporal determiner meaning separate from the preposition was the desire to keep the semantics of *before* and *after* the same whether they take NPs or sentences as complements. Since German complementizers are morphologically distinct from the corresponding prepositions, it may be that they embody the determiner meaning as well; this will explain why quantificational arguments in German do not take scope over the determiner of a temporal clause, and hence why German lacks dependent-time readings.

3.3. Restrictions on scope taking

3.3.1. *Downward-monotone quantifiers*

The difference between single-time and dependent-time readings lies in the relative scope of the implicit temporal determiner and the generalized quantifier within the temporal clause. Thus, both single-time and dependent-time readings are predicted when the subject of the temporal clause is a negative generalized quantifier like *no executive*.

(87) Bill cried after no executive resigned.

a. Single time: $\exists i[i \subseteq \hat{\imath} \wedge \neg\exists x[\mathbf{exec}(x) \wedge \mathbf{resign}(x)(i)] \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]$

b. Dependent time: $\neg\exists x[\mathbf{exec}(x) \wedge \exists i[i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i) \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]]$

The single-time reading (87a) states that Bill cried after some point in time during which no executive resigned, while the dependent-time reading (87b) states that there is no executive whose resignation was followed by Bill's crying. These readings are logically independent: if Bill never cried, the former is false and the latter is true; if Bill cried twice, once after an executive resigned and again after a time in which no executive resigned, then the former is true and the latter is false.

Dependent-time readings that depend on the quantifier *no* are very difficult: many speakers refuse to accept (87b) as a reading of (87), and those who do accept it are only inclined to do so when there is a strong supporting context, for instance when *no* contrasts with another quantifier.

(88) As opposed to Mary, who cried after *every* executive resigned, Bill cried after *no* executive resigned.

The difficulty with (87b) is not with the meaning itself, which is perfectly coherent; nor is there a general problem with temporal dependency on negative quantifiers—sentence (89) has the expected meaning.

(89) Bill cried after no resignation.
$\neg\exists i[i \subseteq \hat{\imath} \wedge \mathbf{resignation}(i) \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]$

The difficulty with the dependent-time reading in (87) must therefore originate in the temporal clause itself: it is difficult for the negative generalized quantifier to take scope above the temporal determiner.

Negative inversion can serve as a test for whether the matrix clause is under the scope of a negative quantifier. When a negative adverbial is preposed, an auxiliary is added to the main clause.

(90) After no resignation did Bill cry. (meaning: (89))

A preposed temporal clause with a negative quantifier but without negative inversion only has a single-time reading (91). This is what we expect, because single-time readings ensue when the quantificational argument of the temporal clause does not take scope over the main clause.

(91) After no executive resigned, Bill cried. (meaning: (87a))

With negative inversion we would expect a dependent-time reading, because these are the readings in which the negative generalized quantifier takes scope over the main clause. But (92) has the same status as (87b)—unacceptable to many, difficult for some.

(92)?After no executive resigned did Bill cry. (meaning (87b) difficult)

Other downward monotone generalized quantifier arguments also result in marginally acceptable dependent-time readings.

(93) Bill cried after few executives resigned.

?"there are few executives such that Bill cried after they resigned"; cf. *Bill cried after few resignations*.

(94) Bill cried after at most three executives resigned.

?"there are at most three executives such that Bill cried after they resigned"; cf. *Bill cried after at most three resignations*.

Since dependent-time readings come from a wide-scope interpretation of a quantificational argument relative to the implicit temporal determiner, we can state this observation as a constraint on semantic derivations: downward monotone quantifiers generally do not take scope over quantifiers that originate in higher syntactic positions. This fits with an observation by Liu (1990), reported by Szabolcsi and Zwarts (1993:237), that downward monotone object generalized quantifiers generally do not take scope over the subject.

We should also note that the restriction (70) from section 2.9 prohibits negative generalized quantifiers from taking scope between the contextualization operation and the implicit temporal determiner. The restriction is needed for the same reasons that led to its original formulation: such a quantifier would lock the free temporal context variable under a negation operator, resulting in a nonsensical reading.

(95) Bill cried after no executive resigned $\rightsquigarrow$
$$*\exists i[\neg\exists x[\mathbf{exec}(x) \wedge i \subseteq \hat{\imath} \wedge \mathbf{resign}(x)(i)] \wedge \exists i'[i' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{cry}(\mathbf{bill})(i')]]$$

The representation in (95) is true if Bill cried after any interval which is outside the context of evaluation; our restriction (70) successfully rules out this derivation.

3.3.2. *Surface order and scope*

There are also restrictions on the relative scope of the temporal clause and quantifiers in the matrix clause. The semantics allows the various scope-taking elements to combine in any order, but not all orders are equally acceptable. As with other constructions that involve scope-taking elements, surface order is often preferred (for recent experimental evidence see Anderson 2004). Thus, some of the speakers I have consulted dislike the wide-scope reading of *each executive* in (72). For these speakers it has about the same status as the wide-scope reading of *every teacher* in the sentence *a student likes every teacher*: dispreferred, but possible. A dependent-time reading is much more natural when the subject *a secretary* is replaced with *a different secretary* or *the same secretary*, which forces the matrix subject to take low scope in order to allow a sentence-internal interpretation of *different* and *same* (Carlson 1987, Barker 2004).

(96) A different secretary cried after each executive resigned.

(97) The same secretary cried after each executive resigned.

Also, when context or world knowledge make the single-time reading unlikely, a dependent-time reading with wide scope for the embedded quantifier is very easily accessible.

(98) A dove is released after each dignitary concludes her speech.

The reading of (98) which is most compatible with our knowledge of the real world is that the dignitaries conclude their speeches at different times, and after each speech a different dove is released.

When the temporal adjunct is preposed it tends to take wide scope, and so do quantifiers within the temporal adjunct. Thus, on the dependent-time reading of sentence (99), it is naturally understood that the secretaries may vary with the executives.

(99) After each executive resigned, a secretary cried.

(On the single-time reading of (99) the scope of *each executive* is restricted to the adjunct clause, so secretaries do not vary: this reading says that one secretary cried at a single point, after a period in which all the executives resigned.)

It has been suggested in the literature that preposed temporal adjuncts necessarily take scope above the entire matrix clause (e.g. Dowty 1979, Hitzeman 1997, but see Abusch and Rooth 1990 for counter-arguments). This is obscured in sentence (99) because the matrix subject *a secretary* is an indefinite, and these are often not subject to scope restrictions that apply to other quantifiers (see e.g. Fodor and Sag 1982, Diesing 1992, Abusch 1993–1994, Reinhart 1997, Kratzer 1998). Thus it is possible to get a dependent-time reading of (99) in which the secretary does not vary with the executives. Context and world knowledge can make such an interpretation more likely, as in the following examples.

(100) Before each government scandal makes it to the news, I talk to a particular member of Parliament. She always knows all the juicy details.

(101) After each spell is cast, a certain magical die is rolled.

(Example 101 is modeled after a sentence from the British National Corpus; thanks to Doug Arnold for help in querying the corpus.)

Non-indefinite quantifiers appear indeed to be incapable of taking scope over a preposed temporal adjunct clause. Thus, while sentence (102) admits a dependent-time reading in which the crying secretaries do not vary with the executives (i.e., few/most secretaries are such, that for each executive they cried after that executive resigned), sentence (103) with a preposed temporal clause does not admit such a reading.

(102) Few/most secretaries cried after each executive resigned.

(103) After each executive resigned, few/most secretaries cried.

The absence of a wide-scope reading of the matrix subject *few/most secretaries* in (103) appears to be due to a property of preposed temporal adjuncts that is not particular to temporal adjunct clauses or to quantifiers within such clauses. I will therefore not pursue an analysis of this phenomenon, but rather refer the reader to the works cited above. We will continue exploring semantic relations *within* temporal adjunct clauses.

3.4. Temporally modified temporal clauses

Our semantics is unable to handle temporal clauses which have temporal modifiers within them, such as the following sentences.

(104) Bill resigned after John disappeared every Friday.

(105) Bill did his homework before daddy came home every evening.

The semantics can interpret these sentences as cascades, where *every Friday* is a modifier of *resigned*, and *every evening* is a modifier of *did his homework*. While these are possible readings, it is more natural to interpret *every Friday* as a modifier of *disappeared* and *every evening* as a modifier of *came home*. But our semantics stipulates that temporally modified clauses are existentially closed (section 2.10), and this does not leave a way to subsequently turn the temporal clause into a temporal generalized quantifier. We therefore need to extend our grammar.

Sentences (104) and (105) show that two extensions of the grammar are needed. The most natural reading of (104) is that Bill resigned after a certain period, in which John disappeared every Friday; such a reading can be captured by subordinating the context of the main clause to the *context* of the temporal clause, which constitutes this period. This is what I call an aggregate reading, and is discussed in section 3.4.1.

The natural reading of (105) is not an aggregate reading; the sentence is true if Bill's dad came home every evening and Bill did his homework every day before his dad's arrival. The homework does not necessarily have to be done in the evening, so this is not a cascaded reading; rather, it is a special kind of dependent-time reading, where the dependency is not on a nominal quantifier but rather on a temporal quantifier inside the temporal clause. Such a reading can be captured by allowing the temporal modifier *every Friday* to apply to a temporal generalized quantifier rather than to an existentially closed sentence. I call this a temporally dependent reading, and these are discussed section 3.4.2.

3.4.1. *Aggregate readings*

Sentence (104), repeated below, is true if Bill resigned after a certain period, in which John disappeared every Friday.

(104) Bill resigned after John disappeared every Friday.

We want to subordinate the temporal context of the main clause to the context of the temporal clause. We start with the familiar clause-type meaning for the temporal clause, derived by applying the temporal generalized quantifier *every Friday* (106) to the contextualized and existentially closed meaning of the sentence *John disappeared* (107).

(106) every Friday $\rightsquigarrow \lambda J \forall i[(i \subseteq \hat{\imath} \wedge \mathbf{friday}(i)) \rightarrow J(i))]$

(107) John disappeared $\rightsquigarrow \exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{disappear}(\mathbf{john})(i')]$

(108) John disappeared every Friday $\rightsquigarrow$
$\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{friday}(i)) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{disappear}(\mathbf{john})(i')]]$

The next step is an "aggregating" operation of abstraction over the temporal context variable of the temporal clause. This gives a temporal property—the set of intervals which can serve as a context for the temporal clause.

(109) John disappeared every Friday $\rightsquigarrow$
$\lambda\hat{\imath}.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{friday}(i)) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{disappear}(\mathbf{john})(i')]]$

This property is contextualized and an existential determiner is applied (110), followed by the preposition *after* (111). The resulting temporal generalized quantifier modifies the main clause (112).

(110) John disappeared every Friday $\rightsquigarrow$
$$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall i'[(i' \subseteq i \wedge \mathbf{friday}(i')) \rightarrow \exists i''[i'' \subseteq i' \wedge \mathbf{disappear}(\mathbf{john})(i'')]] \wedge J(i)]$$

(111) after John disappeared every Friday $\rightsquigarrow$
$$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall i'[(i' \subseteq i \wedge \mathbf{friday}(i')) \rightarrow \exists i''[i'' \subseteq i' \wedge \mathbf{disappear}(\mathbf{john})(i'')]] \wedge J(\mathbf{after}_{\hat{\imath}}(i))]$$

(112) Bill resigned after John disappeared every Friday $\rightsquigarrow$
$$\exists i[i \subseteq \hat{\imath} \wedge \forall i'[(i' \subseteq i \wedge \mathbf{friday}(i')) \rightarrow \exists i''[i'' \subseteq i' \wedge \mathbf{disappear}(\mathbf{john})(i'')]] \wedge \exists i'''[i''' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{resign}(\mathbf{bill})(i''')]]$$

The representation of the sentence has the desired truth conditions: there exists an interval which serves as a context in which John disappeared every Friday, and after this interval, Bill resigned.

3.4.2. *Temporally dependent readings*

Sentence (105), repeated below, is true if Bill's dad came home every evening and Bill did his homework every day before his dad's arrival, though the homework does not necessarily have to be done in the evening.

(105) Bill did his homework before daddy came home every evening.

Neither the aggregate reading nor the cascaded reading have the desired interpretation: the aggregate reading (113) says that Bill did his homework once, before a period in which daddy came home every evening; the cascaded reading (114) entails that Bill did his homework every evening (notice the parameter i on the temporal function **before**). For simplicity, I assume the VPs *did his homework* and *came home* translate as predicate constants (type eit), and that the word *daddy* is a proper name (type e).

(113) Aggregate: $\exists i[i \subseteq \hat{\imath} \wedge \forall i'[(i' \subseteq i \wedge \mathbf{evening}(i')) \rightarrow \exists i''[i'' \subseteq i' \wedge \mathbf{come\text{-}home}(\mathbf{dad})(i')]] \wedge \exists i'''[i''' \subseteq \mathbf{before}_{\hat{\imath}}(i) \wedge \mathbf{do\text{-}hw}(\mathbf{bill})(i''')]]$

(114) Cascaded: $\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{evening}(i)) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{come\text{-}home}(\mathbf{dad})(i') \wedge \exists i''[i'' \subseteq \mathbf{before}_i(i') \wedge \mathbf{do\text{-}hw}(\mathbf{bill})(i'')]]]$

While (113) and (114) are both valid readings of the sentence, the most salient reading is the one described at the beginning of this passage, where the temporal generalized quantifier *every evening* is inside the temporal clause and the evaluation times of the matrix predicate depend on it. The obvious way to derive this temporally dependent reading is to allow temporal generalized quantifiers to modify other temporal generalized quantifiers. I will first demonstrate how this works, and then discuss the implications of such a move.

The raw meaning of the sentence *daddy came home* (115) does not get existentially closed after contextualization, but rather a temporal determiner is applied, making the sentence into a temporal generalized quantifier (116).

(115) daddy came home $\rightsquigarrow \lambda i'.\mathbf{come\text{-}home}(\mathbf{dad})(i')$

(116) daddy came home $\rightsquigarrow \lambda J.\exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{come\text{-}home}(\mathbf{dad})(i') \wedge J(i')]$

This temporal generalized quantifier is modified by the temporal generalized quantifier *every evening* through the rule (54): the free temporal context variable in (116) is bound by the operator $\lambda\hat{\imath}$, and the temporal generalized quantifier *every evening* combines with it through functional composition.

(117) daddy came home every evening $\rightsquigarrow$
$\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \mathbf{evening}(i)) \rightarrow J(i)] \circ$

$$\begin{aligned}&\lambda J \lambda \hat{\imath}.\exists i'[i' \subseteq \hat{\imath} \wedge \textbf{come-home}(\textbf{dad})(i') \wedge J(i')]\\ &= \lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \textbf{evening}(i)) \rightarrow\\ &\qquad \exists i'[i' \subseteq i \wedge \textbf{come-home}(\textbf{dad})(i') \wedge J(i')]]\end{aligned}$$

The result is a temporal generalized quantifier, as expected, which can combine with *before* (118) and modify the matrix clause (119).

(118) before daddy came home every evening $\rightsquigarrow$

$$\begin{aligned}&\lambda J.\forall i[(i \subseteq \hat{\imath} \wedge \textbf{evening}(i)) \rightarrow\\ &\qquad \exists i'[i' \subseteq i \wedge \textbf{come-home}(\textbf{dad})(i') \wedge J(\textbf{before}_{\hat{\imath}}(i'))]]\end{aligned}$$

(119) Bill did his homework before daddy came home every evening $\rightsquigarrow$

$$\begin{aligned}&\forall i[(i \subseteq \hat{\imath} \wedge \textbf{evening}(i)) \rightarrow\\ &\quad \exists i'[i' \subseteq i \wedge \textbf{come-home}(\textbf{dad})(i') \wedge\\ &\qquad \exists i''[i'' \subseteq \textbf{before}_{\hat{\imath}}(i') \wedge \textbf{do-hw}(\textbf{bill})(i'')]]]\end{aligned}$$

This is indeed the desired temporally dependent reading of the sentence: every evening daddy came home, and before that—not necessarily in the evening—Bill did his homework.

Temporally dependent readings are only available with a subclass of temporally modified temporal clauses, so this kind of derivation must be restricted. The data are not very clear, and a precise characterization of the temporally modified clauses which allow dependent readings will have to wait for a further study. In the remainder of the section I will survey the data in order to reach some preliminary conclusions.

We start by noting that there is a clear contrast between sentence (120), with a universally quantified argument, and (121), with a universally quantified temporal modifier.

(120) John got angry after each executive cried.

(121) John got angry after Bill cried during each meeting.

The salient reading of (120) is a dependent reading, where John gets angry after each crying; also available is a single-time or aggregate reading where he only gets angry after all of the cryings. Sentence (121) works the opposite way—the aggregate reading is the salient one. Moreover, while it is possible to understand (121) as reporting an instance of John getting angry after each time Bill cried, the natural interpretation is that John got angry during each meeting; this is a cascaded reading, where *after Bill cried* and *during each meeting* are independent modifiers of the main clause. The sentence does not seem to allow for the possibility that Bill cries during each meeting and John gets angry afterwards, possibly after the meeting, which is what would be expected of a true temporally dependent reading. This could be due to one of two factors: either the grammar doesn't provide a temporally dependent reading, or the grammar provides one but it is ruled out on pragmatic or contextual grounds.

We therefore want to look at cases where a cascaded reading is pragmatically implausible. Here too we see a contrast between universally quantified arguments (122)–(123) and temporal modifiers (124).

(122) John showered before each witness testified.

(123) John showered before he interrogated each witness.

(124) John showered before he testified during each hearing.

Plausible or not, sentences (122)–(123) clearly have readings that state that John showered before each testimony or interrogation. But the only interpretation of (124) which allows for a shower before each testimony is one where John showers during each hearing, despite the fact that it is more plausible for a person to shower before a hearing than during one. Since the absence of a temporally dependent reading in (124) is not likely to be the result of pragmatic factors we conclude that the grammar does not offer such an option.

When we replace the preposition *during* in (124) with *at*, a temporally dependent reading (which is true if John showers before each hearing) is much more readily available.

(125) John showered before he testified at each hearing.

The contrast between *during* and *at* is rather consistent. The following pairs of sentences are designed to exclude aggregate readings: in the examples in (126), the adverb *differently* excludes a single preparation for all hearings, while in the examples in (127) the matrix clause must depend on the temporal generalized quantifier *every meeting* in order to allow the reference of the pronoun *it* to vary with that of its antecedent *a check*.

(126) a. The lawyer prepared differently before he testified at each hearing.
b. The lawyer prepared differently before he testified during each hearing.

(127) a. After John gave me a check at each meeting, he canceled it.
b. After John gave me a check during each meeting, he canceled it.

Sentence (126a) allows for the preparation to occur before each hearing (temporally dependent reading); sentence (126b) strongly implies that the preparation took place during the hearings (cascaded reading). Sentence (127a) allows for the cancellation of each check to follow the meeting in which it was given (temporally dependent reading), whereas sentence (127b) is barely intelligible—it seems like the natural choice would be to give it an aggregate reading, but such a reading would not find an antecedent for the pronoun *it*; to the extent that the NP *a check* can be forced as the antecedent for *it*, we get a cascaded interpretation, where each check was canceled during the meeting in which it was given.

The generalization is that temporally dependent readings are not available for temporal clauses that contain a temporal PP headed by *before*, *after* or *during*. We have seen examples with *during*; now let's look at an example with *before*.

(128) After the instructor typed his notes before each class, he posted them on the web.

The sentence is very difficult to parse. A temporally dependent reading would make the sentence true if the instructor typed his notes before each class, and after each typing—possibly after the class—he posted them on the web. As far as I can tell this is not a possible reading.

Where does this discussion leave us? Temporally dependent readings are the only derivations in which a temporal modifier applies to a clause which is a temporal generalized quantifier rather than to an existentially closed clause. We can stipulate that temporal generalized quantifiers headed by *before*, *after* and *during* only modify existentially closed sentences, while temporal generalized quantifiers that lack a temporal preposition or that are headed by *at* also modify clauses that are temporal generalized quantifiers. This seems rather arbitrary, but at the moment I do not have a principled explanation.

4. Discussion

Section 3 showed how the scopal properties of quantificational arguments in temporal adjunct are characterized using the framework developed in section 2. I will now compare my approach to the other works on temporal generalized quantifier theory. As I pointed out in the beginning of section 2, my choice of syntax-semantics interface stands somewhere between the strict categorial grammar of Francez and Steedman (to appear) and the abstract syntactic logical forms of von Stechow (2002). Below I discuss two cases where my approach fares empirically better. In 4.1 I show that some single-time readings cannot be captured with aggregate derivations, as required by the architecture of Francez and Steedman (to appear); in 4.2 I demonstrate that long-distance temporal dependencies do not necessarily support a need for quantifying into temporal PPs, as is the claim in von Stechow (2002). These are not going to be knock-down arguments in favor of my architecture and against the others, but these issues would require some ingenuity in order to be properly addressed in the other frameworks.

4.1. LEXICALIZED DETERMINERS AND SCOPE

Francez and Steedman (to appear) cast their analysis in the highly lexicalized Combinatory Categorial Grammar (Steedman 1996, 2000). This framework does not admit implicit semantic constructs which are not realized in the syntax, such as our operations of contextualization, existential closure, and the implicit temporal determiner. Instead of being introduced during the derivation, these constructs are attached to lexical items: all verb meanings and common noun meanings are considered to come from the lexicon already contextualized, and verb meanings additionally receive a determiner meaning in the lexicon. Our existential closure is replaced by an operation of *finalization*, which turns an existential temporal generalized quantifier into an existentially closed statement by applying it to the trivial temporal predicate $\lambda i.\mathbf{true}$, which is true of any time interval.

(129) $\lambda J.\exists i[\mathbf{pred}(i) \wedge J(i)](\lambda i.\mathbf{true}) = \exists i[\mathbf{pred}(i)]$

Finalization only applies at the very end of a derivation. (Pratt and Francez 2001 also use an existential determiner with finalization where I use existential closure; they do not motivate this with considerations of the syntax-semantics interface.)

The upshot of all this is that contextualization and an existential determiner necessarily apply before any constituent meanings combine through syntactic derivation. This leads to dependent-time readings when a temporal clause has a quantificational argument, and to temporally dependent readings in case of a temporal modifier within a temporal clause. This is obviously not good enough, so Francez and Steedman add a means of achieving aggregate readings through an additional translation for the preposition *after* which does the following: it applies the temporal generalized quantifier argument to the trivial temporal predicate, resulting in an existentially closed statement; contextualizes the resulting meaning; applies an existential determiner; and injects the temporal function **after** to the appropriate place.

(130) after $\rightsquigarrow \lambda \mathcal{T}^{(it)t}\lambda J.\exists i[i \subseteq \hat{\imath} \wedge [\lambda\hat{\imath}.\mathcal{T}(\lambda i.\mathbf{true})](i) \wedge J(\mathbf{after}_{\hat{\imath}}(i))]$

Francez and Steedman do not discuss single-time readings, but the architecture of the theory precludes a mechanism akin to our single-time derivations: the implicit temporal determiner cannot apply above a quantificational argument because it is built into the verb meaning. Therefore, single-time readings can only be the result of an aggregate derivation.

In many cases, single-time and aggregate readings are barely distinguishable. Francez and Steedman give the following example.

(131) After every girl smiled, Mary applauded.

The sentence is true even if the girls do not smile together, as long as Mary applauds (once) after all the smilings have taken place (a similar reading has been noted by Cresswell 1977 for sentences like *John polishes every boot*). The aggregate reading is derived in our system by subjecting the existentially closed sentence *every girl smiled* (132) to the aggregating operations, resulting in a temporal generalized quantifier (133) which combines with *after* and modifies the main clause (134) (Francez and Steedman's derivation is slightly different but it leads to essentially the same result).

(132) every girl smiled $\rightsquigarrow \forall x[\mathbf{girl}(x) \rightarrow \exists i'[i' \subseteq \hat{\imath} \wedge \mathbf{smile}(x)(i')]]$

(133) every girl smiled $\rightsquigarrow$
$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{girl}(x) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{smile}(x)(i')]] \wedge J(i)]$

(134) after every girl smiled, Mary applauded $\rightsquigarrow$
$\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{girl}(x) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{smile}(x)(i')]]$
$\wedge \exists i''[i'' \subseteq \mathbf{after}_{\hat{\imath}}(i) \wedge \mathbf{applaud}(\mathbf{mary})(i'')]]$

We can compare the final result to the single-time reading of the same sentence, produced by the derivation strategy of section 3.1.

(135) after every girl smiled, Mary applauded $\rightsquigarrow$
$\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{girl}(x) \rightarrow \mathbf{smile}(x)(i)]$
$\wedge \exists i''[i'' \subseteq \mathbf{after}(i) \wedge \mathbf{applaud}(\mathbf{mary})(i'')]]$

The formulas are indeed very similar: the only difference between them is that where the single-time formula (135) has $\mathbf{smile}(x)(i)$, the aggregate formula (134) has $\exists i'[i' \subseteq i \wedge \mathbf{smile}(x)(i')]$. The single-time reading entails the aggregate reading, casting doubt on whether the single-time derivation is needed at all.

There are cases, however, where the aggregate reading is too permissive; this happens with non-persistent predicates such as *smiled exactly once* or *smiled at most three times* (thanks to Ariel Cohen for pointing me in this direction).

(136) After every girl smiled exactly once, Mary applauded.

Imagine a situation in which Alice smiles, then Barbara smiles, then Barbara smiles again, then Christine smiles, and then Mary applauds. The sentence is false: there is no interval in which each girl smiled exactly once, and after which Mary applauded. Yet the aggregate derivation would require only that there exist an interval in which for every girl there exists a subinterval in which she smiled exactly once, and this comes out to be true. I will now show how this is derived formally.

The desired representation of *smiled (exactly) once* should be true of an individual x in an interval i if and only if the total number of intervals at which x smiles in i is exactly one (glossing over the problems of interval individuation and persistence). I will use the following notation, based loosely on Kamp and Reyle (1993:455), to represent the total number of intervals for which some property f holds.

(137) $\sum_{i} f(i)$

The adverb *exactly once* receives the following translation (for the sake of simplicity I do not analyze the constituent *exactly once*).

(138) exactly once $\rightsquigarrow \lambda I \lambda i. \left|\sum_j j \subseteq i \wedge I(j)\right| = 1$

Applying the meaning of *exactly once* to a temporal predicate I returns a temporal predicate I', such that I' is true of any interval i in which the number of subintervals at which I takes place is exactly one. The adverbial *exactly once* combines with the meaning of the (temporal) verb *smiled* in a straightforward manner through functional composition.

(139) smiled exactly once $\rightsquigarrow \lambda x \lambda i.\mathbf{smile}(x)(i) \circ \lambda I \lambda i. \left|\sum_j j \subseteq i \wedge I(j)\right| = 1$
$= \lambda x \lambda i. \left|\sum_j j \subseteq i \wedge \mathbf{smile}(x)(j)\right| = 1$

At this point the single-time and aggregate derivations diverge. A single-time derivation for sentence (136) yields the representation (140) while an aggregate derivation results in the representation (141).

(140) Single-time reading:
$\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{girl}(x) \rightarrow \left|\sum_j j \subseteq i \wedge \mathbf{smile}(x)(j)\right| = 1]$
$\wedge \exists i'[i' \subseteq \mathbf{after}(i) \wedge \mathbf{applaud}(\mathbf{mary})(i')]]$

(141) Aggregate reading:
$\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{girl}(x) \rightarrow \exists i'[i' \subseteq i \wedge \left|\sum_j j \subseteq i' \wedge \mathbf{smile}(x)(j)\right| = 1]]$
$\wedge \exists i''[i'' \subseteq \mathbf{after}(i) \wedge \mathbf{applaud}(\mathbf{mary})(i'')]]$

The single-time reading is the desired one—it is true if there exists an interval during which every girl smiled exactly once, and after which Mary applauded; the aggregate derivation is inadequate, because the subformula $\exists i'[\cdots]$ in the resulting reading allows the sentence to be true even if Mary applauds after an interval in which some of the girls smiled more than once, contrary to the actual meaning of the sentence.

Our conclusion is that aggregate derivations are not suitable replacements for single-time derivations: the grammar must have a way of generating true single-time meanings. Moreover, aggregate derivations need to be blocked for temporal clauses with non-persistent predicates, in order to exclude undesirable readings like (141). The precise characterization of the derivations that should be blocked remains to be determined.

4.2. LONG-DISTANCE DEPENDENCIES AND QUANTIFYING-IN

Long-distance temporal dependencies are used by von Stechow (2002) as an argument for replacing the framework of Pratt and Francez (2001) with one that allows quantifying into temporal PPs (Pratt and Francez do not deal with such dependencies). Long-distance dependencies occur in the following examples, which von Stechow (2002:775) quotes from Larson (1990:170) who attributes them to Geis (1970).

(142) I saw Mary in New York before she claimed that she would arrive.

(143) I encountered Alice after she swore that she had left.

These sentences are ambiguous: sentence (142), for instance, can express either of the two temporal relations below.

(144) a. I saw Mary before the time she made the claim.
b. I saw Mary before her claimed time of arrival.

The ambiguity looks similar to ambiguities in related sentences with relative clauses or questions.

(145) I saw Mary in New York before the time at which she claimed that she would arrive.

(146) When did Mary claim that she would arrive?

Analyses of long distance temporal dependencies explain the ambiguity in all these sentence types using the same mechanisms, be it extraction (Geis 1970, Larson 1990) or Montague-style quantification (Stump 1985). Hence, goes von Stechow's argument, a quantificational analysis of temporal adjunct clauses should allow a mechanism of quantifying into temporal PPs.

However, the similarity between the sentence types breaks down when the temporal clause has a quantificational argument. The following sentences do not have comparable readings.

(147) I saw Mary after each boy claimed that she left.

(148) When did each boy claim that Mary left?

Sentence (148) has a "pair-list" reading with a long-distance temporal dependency, which can be answered with "Adam claimed that she left at noon, Bill claimed that she left at 13:00, and Charles claimed that she left at 13:30".

But sentence (147) does not have a comparable long-distance dependent-time reading, which entails that I saw Mary after each claimed departure time. Indeed, such a reading (149d) is conspicuously absent, given the other readings of the sentence.

(149) a. Short aggregate: I saw Mary after the last act of claiming.

b. Long aggregate: I saw Mary after the the latest claimed departure time.

c. Short dependent-time: I saw Mary after each act of claiming.

d. NOT long dependent-time: I saw Mary her after each claimed departure time.

The absence of long distance dependent-time readings can be illustrated, perhaps more clearly, if we eliminate the short distance readings by putting the verb of the temporal clause in the present tense. The following sentence only has an aggregate reading.

(150) I saw Mary after each boy claims that she left.

a. Aggregate: I saw Mary after the the latest claimed departure time.

b. NOT dependent-time: I saw Mary after every claimed departure time.

The difference between long distance dependencies in temporal clauses and in questions raises the question, whether the same kind of analysis will work for both constructions. If we adopt von Stechow's suggestion of using a movement mechanism, then we have to make sure this mechanism blocks long distance dependent-time readings in temporal adjunct clauses but allows long distance pair-list readings in questions. Alternatively, we can give up the idea that such readings for temporal adjunct clauses are the result of a movement or scope mechanism.

(An anonymous reviewer points out that long distance dependent-time readings may be available in some cases, and gives the examples *I was meeting with Mary when each boy said I shouldn't* and *I telephoned Mary when each boy told me to*. I find it difficult to get the desired readings. At any rate, even if some speakers do accept that these readings exist, they are much less readily available than in the corresponding questions *When did each boy say I shouldn't meet Mary?* and *When did each boy tell me to telephone Mary?* So the problem still remains, but should be recast as a question of why long distance dependent-time readings are extremely difficult rather than impossible. Since the current framework does not deal with gradient acceptability, and since the acceptability of long distance dependent-time readings is still questionable, I will continue to develop the analysis on the assumption that these readings should not be generated by the grammar.)

The following explanation follows naturally from the framework developed in this paper. The event time of a temporal clause is made available for quantification through the combination of a temporal determiner and a temporal property denoted by the verb; this does not give the temporal determiner access to the event time of an embedded clause. But in an aggregate derivation, an extra abstraction operation takes place over the context of the temporal clause. This abstraction can be over the context of an embedded clause within the temporal clause, giving rise to a long-distance dependency. The remainder of this section sketches how the formal analysis can capture this basic idea; a full treatment of embedded clauses would go beyond the scope of this paper, and will have to wait for another occasion.

Verbs with sentential complements take propositions (sentence intensions) as arguments; in order to represent such sentences we will enrich our ontology with an additional type s for possible worlds, as well as enrich our language with a set of variables w, w', $\ldots$ of this type. Following the convention for temporal context variables, the actual world is represented by the free variable $\hat{w}$; intensions are formed through abstraction over this variable. World indices do not concern us much, and they will be set as subscripts in order to reduce visual clutter in the formulas.

Embedded clauses are evaluated with respect to a temporal context. This context does not have to be included in the context of the main clause, as is evidenced by the fact that each clause can have an independent modifier: *Last week Bill thought that Brutus murdered Caesar in the year 40 B.C.* An anonymous reviewer reminds me that the contexts of a main clause and an embedded clause are not really independent—for instance, the tense system ensures that in the sentence *Bill thought that Brutus murdered Caesar*, the context of the embedded clause must precede the event time of the main clause. But for the purposes of this brief exposition we can treat the contexts of the two clauses as independent, so each gets its own free temporal context variable (in a more thorough treatment, the tense system will place conditions relating the time variables in the two clauses).

(151) Bill thought that Brutus murdered Caesar $\rightsquigarrow$

$$\exists i[i \subseteq \hat{\imath} \wedge \\ \quad \mathbf{think}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{murder}_{w}(\mathbf{caesar})(\mathbf{brutus})(j)])(\mathbf{bill})(i)]$$

This means that our formulas are not interpreted with respect to a model and just one temporal index, but rather with respect to a model and several temporal indices—as many as there are independent "reference times".

We now derive the meaning of the temporal clause *after each boy claimed that Mary left*. I will assume that the intension of an embedded sentence is formed at the the CP level by abstracting over the free world variable after the sentence has been contextualized and existentially closed. The sentence *(that) Mary left* has the extension (152) and the intension (153).

(152) (that) Mary left $\rightsquigarrow \exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{\hat{w}}(\mathbf{mary})(j)]$

(153) (that) Mary left $\rightsquigarrow \lambda\hat{w}.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{\hat{w}}(\mathbf{mary})(j)]$

Complement-taking verbs like *claim* (154) take propositions as their complements; the VP *claimed that Mary left* receives its raw meaning in a straightforward way (155).

(154) claimed $\rightsquigarrow \lambda\phi^{st}\lambda x\lambda i.\mathbf{claim}_{\hat{w}}(\phi)(x)(i)$

(155) claimed that Mary left $\rightsquigarrow$
$\lambda x\lambda i.\mathbf{claim}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{w}(\mathbf{mary})(j)])(x)(i)$

Various derivations allow a VP like (155) to end up in a temporal clause like *after every boy claimed that Mary left*. Single-time and dependent-time readings are the result of contextualizing the VP and applying a temporal existential determiner, either above or below the quantificational subject. The result is a temporal generalized quantifier that relates a temporal property (J in the formulas below) to the thinking time i.

(156) Single-time:
$$\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{boy}(x) \rightarrow \mathbf{claim}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{w}(\mathbf{mary})(j)])(x)(i)] \wedge J(i)]$$

(157) Dependent-time:
$$\lambda J.\forall x[\mathbf{boy}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{claim}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{w}(\mathbf{mary})(j)])(x)(i) \wedge J(i)]]$$

In an aggregate derivation, the temporal determiner does not apply to the verb; rather, the verb is existentially closed, and then an abstract is formed over a free temporal context variable.

(158) Existentially closed:
$$\forall x[\mathbf{boy}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{claim}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{w}(\mathbf{mary})(j)])(x)(i)]]$$

At the point of abstraction, we have a choice: we may abstract over the temporal context variable of the temporal clause, or over that of the embedded clause.

(159)
$$\left\{\begin{matrix}\lambda\hat{\imath} \\ \lambda\hat{\jmath}\end{matrix}\right\} \forall x[\mathbf{boy}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{claim}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{w}(\mathbf{mary})(j)])(x)(i)]]$$

The abstraction operation is followed by contextualization and a temporal determiner. We get two distinct temporal generalized quantifiers, depending on which temporal context variable was targeted by the abstraction operation.

(160) $\lambda J.\exists i[i \subseteq \hat{\imath} \wedge \forall x[\mathbf{boy}(x) \rightarrow \exists i'[i' \subseteq i \wedge \mathbf{claim}_{\hat{w}}(\lambda w.\exists j[j \subseteq \hat{\jmath} \wedge \mathbf{leave}_{w}(\mathbf{mary})(j)])(x)(i')]] \wedge J(i)]$

(161) $\lambda J.\exists j[j \subseteq \hat{\jmath} \wedge \forall x[\mathbf{boy}(x) \rightarrow \exists i[i \subseteq \hat{\imath} \wedge \mathbf{claim}_{\hat{w}}(\lambda w.\exists j'[j' \subseteq j \wedge \mathbf{leave}_{w}(\mathbf{mary})(j')])(x)(i)]] \wedge J(j)]$

The temporal generalized quantifier (160) relates the temporal property variable J to the temporal context variable i which is associated with the time of claiming, just as in (157) above. The temporal generalized quantifier (161), on the other hand, relates the temporal property variable J to the temporal context variable j which is associated with the leaving time.

Our system therefore succeeds in making the prediction that long distance temporal dependencies are only possible with aggregate interpretations. The reason is that the creation of temporal generalized quantifiers can only access the topmost event-time variable, but the abstraction in an aggregate derivation can access the context of embedded clauses as well. I do not see a straightforward way to capture this with a quantifying-in approach.

Arnim von Stechow and an anonymous reviewer point out that the abstraction operation in an aggregate derivation must have a syntactic correlate that relates it to the position of the clause whose temporal context variable is abstracted over. This is because long-distance temporal dependencies are subject to locality conditions ("islands"), an observation that Larson (1990:171) attributes to Geis (1970). For example, it is impossible to have temporal dependency on a clause embedded inside an NP.

(162) I saw Mary after Bill made the claim that she left.

a. I saw Mary after the act of claiming.

b. NOT: I saw Mary after the claimed departure time.

We have seen that long-distance dependencies in temporal adjunct clauses are different from those in questions, supporting an analysis that uses abstraction in an aggregate derivation rather than extraction. However, we must make sure that abstraction over the context of an embedded clause is subject to the same locality conditions as other long-distance dependencies. I leave the precise syntactic formulation as a problem for further study.

5. Conclusion

This paper has shown how a treatment of temporal clauses as temporal generalized quantifiers explains the scopal properties of quantificational adjuncts in temporal adjunct clauses. It has also provided a classification of the various readings that obtain in these structures, and a formal semantics that characterizes these readings. The semantics is articulated in a framework which introduces implicit semantic operations at various syntactic nodes. This final section reviews these operations, the interactions between them, and the constraints on their application.

Contextualization (12a) applies to all temporal nouns, and all verbs.

Existential closure (13a) applies at the top of the clause to all clauses that are not temporal modifier clauses, as well as to temporal modifier clauses in an aggregate derivation. It always applies to contextualized properties.

An implicit temporal determiner (27) applies at the top of the clause to temporal modifier clauses which are not temporally modified, as well as to temporal modifier clauses which are modified by a bare temporal NP or a temporal PP headed by *at*; it also applies to temporal common nouns that lack an explicit determiner. It always applies to contextualized properties.

Temporal modification (54) involves abstraction over the temporal context variable of the temporally modified constituent.

Abstraction is also performed over the temporal context variable of a temporal modifier clause in an aggregate derivation.

Quantificational arguments and temporal modifiers (nominal and temporal generalized quantifiers) may take scope over the existential closure operation (13a) or the implicit temporal determiner (27); this has the effect of applying existential closure or a temporal determiner at a lower level, close to the verb. However, a downward monotone quantifier does not generally take scope above a temporal determiner (section 3.3.1), and a universal or negative generalized quantifier is prohibited from intervening between a contextualized temporal property and its determiner (70).

The characterization of the above operations is pretty well defined: once we know whether or not a clause acts as a temporal modifier, we are fairly certain as to which derivations it can undergo. But the expression “in an aggregate derivation”, which repeats itself twice in the above characterizations, is not well defined: we still need to determine when exactly such derivations are allowed.

Aggregate derivations were introduced in section 3.4.1 in order to capture the semantics of temporally modified temporal clauses (e.g. *when John disappeared every Friday*). In section 4.1 we saw that aggregate derivations give incorrect truth conditions for temporal clauses with non-persistent predicates (*after each girl smiled exactly once*); then in section 4.2 we saw that aggregate derivations are necessary in order to get temporal dependency on a clause embedded within a temporal clause (*after Bill claims that Mary left*). Aggregate derivations must therefore be allowed in general, but blocked for temporal clauses with non-persistent predicates. It is hard to see how such a restriction can be enforced, so for want of a better explanation I take it to be a constraint on derivations.

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