Temporal Prepositions and Temporal Generalized Quantifiers

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Abstract

In this paper, we show how the problem of accounting for the semantics of temporal preposition phrases (tPPs) leads us to some surprising insights into the semantics of temporal expressions in general. Specifically, we argue that a systematic treatment of English tPPs is greatly facilitated if we endow our meaning assignments with *context variables*, a device which allows a tPP to restrict domains of quantification arising elsewhere in a sentence. We observe that the use of context variables implies that tPPs can modify expressions in two ways, and we use this observation to predict the behaviour of tPPs whose components are themselves modified by other tPPs.
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1 Overview

It is widely accepted that a simple assertive sentence such as

(1) Mary kissed John

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makes an existential claim, namely, that an event of a certain type—in this case, that of Mary's kissing John—occurred within some contextually determined interval. Certainly, such existential claims are present when additional, explicit, temporal quantification is provided by temporal preposition phrases (tPPs), for example:

(2) Mary kissed John during every meeting,

(3) Mary kissed John during every meeting one Monday.

Here, the existential quantification present in sentence (1) falls within the scope of the universal quantification over meetings in sentence (2), and this universal quantification in turn falls within the scope of the existential quantification over Mondays in sentence (3). This paper presents a semantic theory of temporal prepositions, with emphasis on their role in temporal quantification. Central to this theory is the concept of a *temporal generalized quantifier*—a device which allows us to equip meanings of various phrases with a variable representing *temporal context*. We show how our approach deals in a natural way with examples that cause difficulties for other semantic theories found in the literature.

The relationship between sentences (1)—(3) can be described formally as follows. We represent the temporal context by means of lambda-abstracted *context variable* I, and we quantify over events occurring within that time interval by means of an *object variable* x_0. Then sentence (1) might reasonably be interpreted as:

(4) $[\![_{\mathrm{S}}\textsf{Mary kissed John}]\!] =$
$\lambda I[\exists x_0(\textsc{kiss}(\textsc{mary},\textsc{john})(x_0) \wedge \mathrm{time}(x_0) \subseteq I)]$.

We assume that $\textsc{kiss}(\textsc{mary},\textsc{john})(x)$ is satisfied by x just in case x denotes an event of Mary's kissing John, and that the function $\mathrm{time}(x)$ maps an event to the time interval over which it occurs. The reason for treating the temporal context using the variable I in this way will emerge in the course of the paper; for now, we can suppose that the value of this variable is supplied by the context of utterance, and is presumably constrained by the verb-tense to be prior to the time of utterance.

A slight change of notation will prove helpful later. We define the second-order relations **a**, **every** and **the** in the familiar way, thus:

(5) $[\![_{\mathrm{Det}}\textsf{a}]\!] = \lambda Q\lambda P[\mathbf{a}(Q,P)] =_{\mathrm{def}} \lambda Q\lambda P[\exists x(Q(x) \wedge P(x))]$

(6) $[\![_{\mathrm{Det}}\textsf{every}]\!] = \lambda Q\lambda P[\mathbf{every}(Q,P)] =_{\mathrm{def}} \lambda Q\lambda P[\forall x(Q(x) \rightarrow P(x))]$

(7) $[\![_{\mathrm{Det}}\textsf{the}]\!] = \lambda Q\lambda P[\mathbf{the}(Q,P)] =_{\mathrm{def}} \lambda Q\lambda P[\exists! x(Q(x)) \wedge \exists x(Q(x) \wedge P(x))]$.

Then we can re-write (4) as

(8) $[\![_{\mathrm{S}}\textsf{Mary kissed John}]\!] =$
$\lambda I[\mathbf{a}(\lambda x_0[\textsc{kiss}(\textsc{mary},\textsc{john})(x_0) \wedge \mathrm{time}(x_0) \subseteq I], \top)]$,

where $\top$ denotes the trivial property satisfied by everything. Of course, this change is purely cosmetic.

We note two controversial issues in passing. First, for the sake of concreteness, we have adopted a Russellian approach to definite descriptions; however, this approach could be replaced, without affecting the substance of this paper, by alternatives based on anaphoric reference or familiarity. Second, the quantificational nature of sentences such as (1) is less clear-cut than we have suggested (see, for example, the discussion in Partee [14], [15], Enc [6] and Ogihara [12]). Certainly, sentences such as Mary kissed every boy/three boys/no boys do not (or at least do not clearly) involve a simple existential quantification over events. However, we cannot illuminate these issues here, and we will therefore concentrate on underlying sentences such as (1) where the event-structure is clear. In fact, our quantificational treatment of such sentences is similar to that proposed by Ogihara (except that we take quantification to be over events rather than time intervals), so we are not proposing anything radically new at this point.

Proceeding similarly, we can give the meanings of sentences (2) and (3) as, respectively:

(9) $[\![_{\mathrm{S}}\text{Mary kissed John during every meeting}]\!] =$
$\lambda I[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)], \top)])],$

(10) $[\![_{\mathrm{S}}\text{Mary kissed John during every meeting one Monday}]\!] =$
$\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge$
$\text{time}(x_0) \subseteq \text{time}(y_0)], \top)])])].$

Such *cascades* of tPPs, as we call them, and the nested quantification they induce, motivate much of the ensuing development.

We draw two conclusions from these examples. The first is that the tPPs in sentences (2) and (3) scope over the existential quantification over kissing events occurring in (1). That is, the tPPs in question apply to meanings in which event-quantification has already occurred—as we shall say, to *determined* meanings. The second is that, as we shall argue, in order to generate the meanings proposed in (9)—(10), the meanings of noun-phrase tPP complements such as every meeting must themselves incorporate a temporal context variable, similar in function to the temporal context variable I encountered above in sentence-meanings. That is, we shall propose that every meeting be no longer interpreted as the familiar generalized quantifier (Barwise and Cooper [2]):

(11) $\lambda P[\mathbf{every}(\lambda x[\text{MEETING}(x)], P)],$

but rather, as the *temporal* generalized quantifier (tGQ):

(12) $[\![_{\mathrm{tNP}}\textsf{every meeting}]\!] = \lambda P \lambda I[\mathbf{every}(\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I], P)]$.

We further argue that this treatment of determiner phrases forces us to adopt a similarly 'relational' view of their noun-complements. Thus, for example, instead of the familiar meaning assignment to the noun meeting:

(13) $\lambda x[\textsc{meeting}(x)]$,

we will be led to propose:

(14) $[\![_{\mathrm{tN}}\textsf{meeting}]\!] = \lambda x \lambda I[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I]$.

We show in sections 2 and 3 how these revisions enable us to give an elegant account of sentences with cascades of tPPs.

A second well-known phenomemnon concerning temporal prepositions is that they can take complements of several categories. Consider, for example:

(15) Jane telephoned John after the meeting,

(16) Jane telephoned John after Mary arrived.

Just as sentence (15) locates Jane's telephoning John with respect to an event picked out by the determiner phrase the meeting, sentence (16) does so with respect to one picked out by the sentence Mary arrived. Now, once we have accepted the revision to noun-phrase meanings proposed in (12), we notice an irresistable similarity of form with the sentence-meaning (8). It is this similarity of form that we use to give a uniform account of sentences (15) and (16).

Specifically, we propose that the meaning (8) be re-written in the form of a schematic tGQ:

(17) $[\![_{\mathrm{S}_1}\textsf{Mary kissed John}]\!] =$
$\lambda P \lambda I[\mathbf{Q}(\lambda x[\textsc{kiss}(\textsc{mary},\textsc{john})(x) \wedge \mathrm{time}(x) \subseteq I], P)]$.

where the quantifying relation $\mathbf{Q}$ is left open. Our original meaning assignment (8), which assumed that the sentence formed a straightforward assertion, is recoverable by setting $\mathbf{Q} = \mathbf{a}$ and instantiating P to the trivial predicate. However, when this sentence appears as a complement of a temporal preposition, such as before or whenever, we will propose alternative settings for $\mathbf{Q}$, and we allow P to be bound by quantification arising elsewhere in the sentence. Sentence meanings (9) and (10) can of course be generalized in a similarly way. Thus, by making some minor changes to the form of sentence meanings, we are able to express them in the form of tGQs, a move which enables us to give a uniform account of the semantics of temporal prepositions which can take both noun-phrase and sentential complements.

Not only can tPPs take both sentences and noun phrases as complements, but they can also modify objects belonging to both categories. Consider, for example:

(18) Jane telephoned John during every meeting on a Monday,

(19) Jane telephoned John whenever Mary arrived on a Monday.

We argue that, on the most natural readings of these sentences, the tPP on a Monday modifies the tPP complements every meeting (a noun phrase) and Mary arrived (a sentence) respectively. Of particular interest here is the fact that the universal quantification is most naturally taken to range over meetings (events of Mary's arriving) occurring on *any* Monday in the given temporal context. That is, the universal quantification scopes higher than the existential quantification introduced by the tPP on a Monday.

Now this observation is particularly striking in the case of sentence (19), where on a Monday modifies the sentence Mary arrived. We argue in the sequel that, in sentence (19), on a Monday modifies an undetermined form of sentence meaning which must look something like

(20) $[\![_{\mathrm{S}_2}\text{Mary arrived}]\!] = \lambda x \lambda I[\text{ARRIVE}(\text{MARY})(x) \wedge \text{time}(x) \subseteq I]$.

The critical point here is that the event-carrying variable x is not bound by quantification when the tPP on a Monday applies. Yet we have also claimed that the tPP during every meeting in sentence (2) modifies a determined sentence meaning in which the event-carrying variable x is already existentially quantified when the tPP applies. So, we are led to recognize two levels of sentence meaning: determined and undetermined. These levels of meaning correspond to the distinction between a noun-phrase meaning and a noun meaning. Only when we draw this distinction, we claim, can we arrive at a correct, systematic account of tPPs whose complements are themselves modified by other tPPs.

To summarize, in seeking a detailed and systematic account of tPPs, able to accommodate cascades of tPPs and tPPs with tPP-modified complements, we are led to a relational view of both noun meanings and (undetermined) sentence meanings, in which an added 'context' argument constrains the occurrence-time of the familiar 'object' argument. We are further led to distinguish two levels of sentence meaning, corresponding to the semantic differences between nouns and noun phrases. The result is a semantic theory which correctly handles intricate quantifier scoping phenomena not dealt with by earlier accounts, and which deals seemlessly with cases where tPPs interact with both sentences and noun-phrases.

A word on notation. We use the variables I, I' etc. to range over time intervals, and the variables x_0, x_1, y_0, y_1 etc. to range over any individuals (but primarily over events). We denote the type (set) of time intervals by $\mathbf{i}$ and the type of all individuals, including time intervals, by $\mathbf{e}$. As usual, the type of truth values is $\mathbf{t} = \{\text{true}, \text{false}\}$. We use the variables P, Q to range over objects of type $(\mathbf{e}, \mathbf{t})$—that is, functions from any individuals (including time intervals) to truth values. We use $\mathcal{P}$ very occasionally for still higher-order variables. Officially, all functions are 1-place, so that we should write, for example, $\lambda x[\lambda y[f(x)(y)]]$ rather than $\lambda x \lambda y[f(x,y)]$; however, we shall lapse into the latter form to make the formulas easier to read. In fact, we often write such things as $\text{KISS}(\text{MARY},\text{JOHN})(x_0)$, just to separate out the event argument x_0 from the 'normal' arguments. No harm is done by these concessions to human frailty.

The plan of the paper is as follows. Section 2 sets out the basic theory, with section 3 providing a justification for some of the proposals made there, as well as a comparison with the existing literature. In particular, we justify the presence of temporal context variables in the meanings of tPPs, sentences and some noun phrases. Section 4 examines tPP modification of noun-phrases and argues for the presence of temporal context variables in the meanings of some nouns, and section 5 extends the parallels between sentence meanings and noun-phrase meanings. In particular, we argue for two levels of sentence meanings, and show how tPPs must be allowed to modify sentences at both levels. Section 6 draws together various loose ends and provides an overview of the preceding detail.

2 The Basic Theory

In this section, we present our account of the semantics of tPPs. This account relies on some specific (and occasionally nonstandard) proposals regarding the semantics of other expressions in English, especially nouns. Rather than justifying each such proposal as it is introduced, we present the whole of the account in one go, leaving detailed justifications for later sections.

2.1 Temporal nouns and temporal noun phrases

According to the standard treatment of nouns and determiners in Montague semantics, meanings are assigned as follows:

(21) $[\![_{\text{N}}\textsf{girl}]\!] = \lambda x[\text{GIRL}(x)]$,

(22) $[\![_{\text{Det}}\textsf{every}]\!] = \lambda Q \lambda P[\mathbf{every}(Q,P)]$,

with the meaning of noun phrases computed by applying the determiner meaning to the noun meaning:

(23) $[\![_{\text{NP}}\textsf{every girl}]\!] =$

$$[\![_{\mathrm{Det}}\textsf{every}\,]\!]([\![_{\mathrm{N}}\textsf{girl}]\!]) =$$
$$\lambda Q\lambda P[\mathbf{every}(Q,P)](\lambda x[\textsc{girl}(x)]) = \lambda P[\mathbf{every}(\lambda x[\textsc{girl}(x)], P)].$$

However, as indicated in the previous section, we shall argue that temporal preposition complements should be taken to incorporate a temporal context variable. These temporal context variables, we propose, originate in the meanings of nouns and verbs. In particular, we propose the semantic assignments:

(24) $[\![_{\mathrm{tN}}\textsf{meeting}]\!] = \lambda x\lambda I[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I]$,

(25) $[\![_{\mathrm{tNP}}\textsf{every meeting}]\!] = \lambda P\lambda I[\mathbf{every}(\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I], P)]$.

Here, the variable I picks out a time interval within which the the meetings in question are constrained to occur. We shall see presently how such context variables allow us to deal with otherwise puzzling features of temporal prepositions. The type of tNP meanings is thus $((\mathbf{e},\mathbf{t}),(\mathbf{i},\mathbf{t}))$; we have already agreed to call objects of this type tGQs.

Before proceeding, however, we need to overcome a technical difficulty: the standard determiner meaning (22) is of the wrong type to apply directly to our proposed noun meaning (24). We could, of course, revise determiner meanings so that they can take these new, contextualized noun meanings as arguments; alternatively, however, we could complicate the way determiners and nouns combine. Since we shall be dealing with context variables throughout this paper, the latter strategy turns out to be more convenient. To see how our solution works, suppose that we could 'suspend' the context variable I in (24), thus:

(26) $\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I]$.

Then we could apply the determiner-meaning as usual,

(27) $\lambda Q\lambda P[\mathbf{every}(Q,P)](\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I]) =$
$\lambda P[\mathbf{every}(\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I], P)]$,

and finally 'restore' the temporal context variable in the appropriate position:

(28) $\lambda P\lambda I[\mathbf{every}(\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I], P)]$.

Making this procedure formally respectable involves a small change to the usual rule for applying determiners to nouns. Let the variable x have any type τ, and the variable Q, type $(\tau, \mathbf{t})$. Let the variables u and v have any types. Remembering that all functions are officially 1-place, the function $\lambda Q\lambda u[\psi(Q,u)]$ (which should really be written $\lambda Q[\lambda u[\psi(Q,u)]]$) is prevented from applying to the argument $\lambda x\lambda v[\phi(x,v)]$ by the interposed λv. We define a form of *pseudo-application* of $\lambda Q\lambda u[\psi(Q,u)]$ to $\lambda x\lambda v[\phi(x,v)]$ by:

(29) $\lambda Q\lambda u[\psi(Q,u)](_1\lambda x\lambda v[\phi(x,v)])_1 =_{\mathrm{Def}} \lambda u\lambda v[\lambda Q[\psi(Q,u)](\lambda x[\phi(x,v)])]$
$= \lambda u\lambda v[\psi(\lambda x[\phi(x,v)], u)]$.

(A second form of pseudo-application will be introduced later: hence the notation $({}_1 \ldots)_1$.) Though definition (29) may look confusing, it is just a formalization of the steps carried out in (26)–(28). Using this notation, we can express the mechanism for combining a determiner meaning with contextualized noun meaning as:

(30) $[\![{}_{\mathrm{tNP}}\textsf{every meeting}]\!] = [\![{}_{\mathrm{Det}}\textsf{every}\ ]\!]({}_1[\![{}_{\mathrm{tN}}\textsf{meeting}]\!])_1$.

For it is then routine to compute:

(31) $[\![{}_{\mathrm{tNP}}\textsf{every meeting}]\!] =$
$\lambda Q\lambda P[\mathbf{every}(Q,P)]({}_1\lambda x\lambda I[\text{MEETING}(x)\wedge\text{time}(x)\subseteq I])_1 =$
$\lambda P\lambda I[\lambda Q[\mathbf{every}(Q,P)](\lambda x[\text{MEETING}(x)\wedge\text{time}(x)\subseteq I])] =$
$\lambda P\lambda I[\mathbf{every}(\lambda x[\text{MEETING}(x)\wedge\text{time}(x)\subseteq I],P)]$,

as required. Other noun phrases can be handled similarly, for example:

(32) $[\![{}_{\mathrm{tN}}\textsf{Monday}]\!] = \lambda x\lambda I[\text{MONDAY}(x)\wedge\text{time}(x)\subseteq I]$,

(33) $[\![{}_{\mathrm{tNP}}\textsf{one Monday}]\!] =$
$[\![{}_{\mathrm{Det}}\textsf{one}]\!]({}_1[\![{}_{\mathrm{tN}}\textsf{Monday}]\!])_1 =$
$\lambda Q\lambda P[\mathbf{a}(Q,P)]({}_1\lambda x\lambda I[\text{MONDAY}(x)\wedge\text{time}(x)\subseteq I])_1 =$
$\lambda P\lambda I[\mathbf{a}(\lambda x[\text{MONDAY}(x)\wedge\text{time}(x)\subseteq I],P)]$.

One difficult issue here is whether noun meanings should *always* be taken to have temporal (or any other kind of) context variable. After all, in many cases, the predicates introduced by nouns such as student, girl, etc. apply to their objects throughout the time of interest, and hence are to all intents and purposes non-temporal. Since this paper is concerned primarily with the semantics of temporal prepositions, we shall henceforth assume that all nouns and noun phrases occurring in verb complements have non-temporal meanings as in (21) and (23), while all nouns and noun phrases occurring as temporal preposition complements have temporal meanings as in (24) and (25). This simplifying assumption lets us concentrate on tPPs while ignoring the often intricate temporal features of nouns occurring as verb complements. Henceforth, then, when we speak simply of *nouns* (Ns) or *noun phrases* (NPs), we assume a non-temporal meaning as in (21) or (23); when we speak of *temporal nouns* (tNs) or *temporal noun phrases* (tNPs), we assume a temporally contextualized meaning as in (24) or (25).

2.2 tPP meanings

Endowing tNP meanings with context variables greatly affects the meanings given to temporal prepositions. Consider, for example, during. We propose:

(34) $[\![{}_{\mathrm{tP}}\textsf{during}]\!] = \lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time}(y_0))],I)]$,

where $\mathcal{P}$ is of type $((\mathbf{e},\mathbf{t}),(\mathbf{i},\mathbf{t}))$—that is, $\mathcal{P}$ ranges over tGQs. We further propose that the meaning of a tPP be computed by applying the meaning of its head temporal preposition to its complement in the ordinary way:

(35) $[\![_{\text{tPP}}\textsf{during every meeting}]\!] = [\![_{\text{tP}}\textsf{during}]\!]([\![_{\text{tNP}}\textsf{every meeting}]\!])$.

It is then simple to compute:

(36) $[\![_{\text{tPP}}\textsf{during every meeting}]\!] =$
$\lambda P \lambda I[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])]$.

Finally, we propose that tPP meanings modify by straightforward function-application, thus:

(37) $[\![_{\text{S}}\textsf{Mary kissed John during every meeting}]\!] =$
$[\![_{\text{tPP}}\textsf{during every meeting}]\!]([\![_{\text{S}}\textsf{Mary kissed John}]\!])$.

(Note: we will have occasion to slightly revise this proposal below.) Given the sentence-meaning:

(38) $[\![_{\text{S}}\textsf{Mary kissed John}]\!] =$
$\lambda I[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY},\text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq I], \top)]$,

it is then simple to compute:

(39) $[\![_{\text{S}}\textsf{Mary kissed John during every meeting}]\!] =$
$\lambda I[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY},\text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)], \top)])]$,

which, as we saw above, is the required meaning. Of course, in taking tPPs to apply to sentence meanings, we are deliberately treading around various delicate syntactic issues regarding the point at which such tPPs attach (see, for example, Verkuyl [22], Hitzeman [8]). Thus, we ignore the question of whether tPPs attach before or after verb subjects or tense markers have been combined. Since, however, we have nothing useful to add on these issues, which do not affect the main thrust of the present paper, we shall continue to apply tPPs to sentences with their subjects already incorporated, and with tense information thrown away.

To illustrate this approach further, consider the tPP one Monday in the sentence

(40) Mary kissed John during every meeting one Monday,

and let us assume that this tPP is headed by a null temporal preposition. Intuitively, one Monday means something like during one Monday, so we propose that the meaning of this null temporal preposition be indentical to that of during. From (33), and re-numbering the variables for clarity, we derive:

(41) $[\![_{\text{tPP}}\emptyset\ \textsf{one Monday}]\!] =$

$$[\![_{\text{tP}}\emptyset]\!]([\![_{\text{tNP}}\textsf{one Monday}]\!]) =$$
$$\lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_1[P(\text{time}(y_1))], I)]($$
$$\lambda P\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], P)]) =$$
$$\lambda P\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])].$$

Whence, from (39) and (41):

(42) $[\![_{\text{S}}\textsf{Mary kissed John during every meeting one Monday}]\!] =$
$[\![_{\text{tPP}}\textsf{one Monday}]\!]([\![_{\text{S}}\textsf{Mary kissed John during every meeting}]\!]) =$
$\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)],$
$\top)])])].$

Thus, the cascading of temporal prepositions is properly handled on our account. We note that English allows tPPs attaching at the same level to be re-ordered without loss of sense, for example: Mary kissed John one Monday during every meeting. In the sequel we shall always silently choose the only sensible order of application of tPP meanings.

Not surprisingly, the temporal prepositions on (when used with day-denoting complements) and in (when used with month-denoting complements) can be given the same meaning as during, this time assuming a suppressed definite quantifier in the relevant tNP complement. Thus,

(43) $[\![_{\text{tPP}}\textsf{on Monday}]\!] = [\![_{\text{tP}}\textsf{on}]\!]([\![_{\text{tNP}}\textsf{(the) Monday}]\!]) =$
$\lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time}(y_0))], I)]($
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\text{MONDAY}(x_1) \wedge \text{time}(x_1) \subseteq I], P)]) =$
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\text{MONDAY}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])],$

(44) $[\![_{\text{tPP}}\textsf{in January}]\!] = [\![_{\text{tP}}\textsf{in}]\!]([\![_{\text{tNP}}\textsf{(the) January}]\!]) =$
$\lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time}(y_0))], I)]($
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\text{JANUARY}(x_1) \wedge \text{time}(x_1) \subseteq I], P)]) =$
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\text{JANUARY}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])].$

It is worth remarking at this point on the very lightweight semantic contribution made by the temporal prepositions considered so far. Intuitively, the word during seems to denote some sort of containment or inclusion relation. Yet the proposed meaning (34) contains no occurrence of $\subseteq$. True, the meaning of the whole tPP during every meeting given in (36) does reveal an occurrence of $\subseteq$, *but not in the way one would expect*. For here, it is the times of the meetings that are constrained to fall within some other interval, not the other way round. What makes the proposed account work, despite the rather unintuitive proposed meaning for during is, of course, the presence of temporal context variables in the sentences which tPPs modify. For the kissing event reported in a sentence like Mary kissed John is already constrained to fall within the time indicated by the temporal context variable; once that context variable is available to the tPP, no other notion of containment is required. We will see in section 3 how

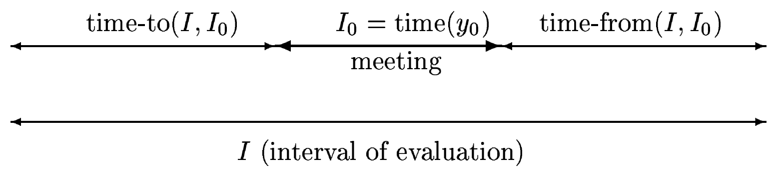

Figure 1: Simple representation of before, during and after.

powerful this idea is.

2.3 More tPP meanings

The temporal prepositions considered so far serve to locate events *within* intervals picked out by their complements. However, the temporal preposition before serves to locate them *prior to* the interval picked out by its complement (symmetrically for after), and it is to these cases that we now turn. We begin by defining the partial functions time-to and time-from:

(45) $\text{time-to}([a,b],[c,d]) =_{\text{Def}} [a,c]$ if $[c,d] \subseteq [a,b]$
$\text{time-from}([a,b],[c,d]) =_{\text{Def}} [d,b]$ if $[c,d] \subseteq [a,b]$.

Intuitively, the role of these functions is to move the interval of subsequent evaluation either forwards or backwards. Let $I_0 = \text{time}(y_0)$ be an interval over which a meeting takes place in some temporal context I. Then the intervals time-to(I, I_0) and time-from(I, I_0) are depicted in fig. 1. Assuming, then, that there is only one meeting within the interval I, events in I can be located during that meeting by means of the tGQ:

(46) $\lambda P \lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])]$.

Likewise, events in I can be located before and after the meeting by means of the tGQs:

(47) $\lambda P \lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))])]$

(48) $\lambda P \lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time-from}(I, \text{time}(y_0)))])]$,

respectively.

The upshot of the above analysis is that the temporal prepositions before and after can be assigned meanings in the same style as during, thus:

(49) $[\![_{\text{tP}}\textsf{before}]\!] = \lambda \mathcal{P} \lambda P \lambda I[\mathcal{P}(\lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))], I)]$

(50) $[\![_{\mathrm{tP}}\textsf{after}]\!] = \lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time-from}(I, \text{time}(y_0)))], I)]$.

To see how this works, we simply compute:

(51) $[\![_{\mathrm{tPP}}$ before the meeting $]\!] = [\![_{\mathrm{tP}}$ before$]\!]([\![_{\mathrm{tNP}}$ the meeting $]\!]) =$
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\textsc{meeting}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))])]$,

(52) $[\![_{\mathrm{tPP}}$ after the meeting $]\!] = [\![_{\mathrm{tP}}$ after$]\!]([\![_{\mathrm{tNP}}$ the meeting $]\!]) =$
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\textsc{meeting}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[P(\text{time-from}(I, \text{time}(y_0)))])]$.

Hence, using the by now familiar patterns of derivation:

(53) $[\![_{\mathrm{S}}$ Mary kissed John before the meeting $]\!] =$
$[\![_{\mathrm{tPP}}$ before the meeting $]\!]([\![_{\mathrm{S}}$ Mary kissed John $]\!]) =$
$\lambda I[\mathbf{the}(\lambda x_1[\textsc{meeting}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\textsc{kiss}(\textsc{mary}, \textsc{john})(x_0) \wedge$
$\text{time}(x_0) \subseteq \text{time-to}(I, \text{time}(y_0))],$
$\top)])]$,

(54) $[\![_{\mathrm{S}}$ Mary kissed John after the meeting $]\!] =$
$[\![_{\mathrm{tPP}}$ after the meeting $]\!]([\![_{\mathrm{S}}$ Mary kissed John $]\!]) =$
$\lambda I[\mathbf{the}(\lambda x_1[\textsc{meeting}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\textsc{kiss}(\textsc{mary}, \textsc{john})(x_0) \wedge$
$\text{time}(x_0) \subseteq \text{time-from}(I, \text{time}(y_0))],$
$\top)])]$,

which are the intuitively correct meanings.

Of course there is much more to be said about the meanings of before and after. For example, before the meeting can also mean *just* or *a short time before the meeting.* That is, it can serve to locate events within (what the context determines to be) a short interval immediately preceeding the meeting. And *before* is often used with a durative modifier as in five minutes before which serves to locate events within (what the context determines to be) a short interval 5 minutes before the (start of) the meeting. The first of these meanings might be given as:

(55) $[\![_{\mathrm{S}}$ Mary kissed John (just) before the meeting $]\!] =$
$\lambda I[\mathbf{the}(\lambda x_1[\textsc{meeting}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\textsc{kiss}(\textsc{mary}, \textsc{john})(x_0) \wedge$
$\text{time}(x_0) \subseteq \text{just-before}(I, \text{time}(y_0))],$
$\top)])]$,

where just-before is another partial function defined by

(56) $\text{just-before}([a, b], [c, d]) = [c - \varepsilon, c]$ if $[c - \varepsilon, d] \subseteq [a, b]$

and ε is a contextually determined parameter. Similarly,

(57) $[\![_{\mathrm{S}}$ Mary kissed John 5 minutes before the meeting $]\!] =$

$$\lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I],$$
$$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge$$
$$\text{time}(x_0) \subseteq \text{5-mins-before}(I, \text{time}(y_0))],$$
$$\top)])],$$

with a suitable definition of 5-mins-before. Corresponding remarks apply to after, of course. A full account of the semantics of temporal prepositions would have to show how pre-posed arguments as in 5 minutes before contributed to these warp-functions, of course. However, we leave the semantics of such arguments for another occasion. (See also Zwarts [24].) Even these observations only scratch the surface of the behaviour of before and after. We cannot investigate this behaviour in depth here. Instead we content ourselves with the claim that the above proposals can be used to give meanings of all the salient senses of before and after in the form of tGQs.

Other temporal prepositions can be handled similarly. Consider until, which is characteristically associated with universal quantification over events or times (cf. by). Thus, assuming that meetings do not go on for months, sentence (58) is acceptable while (59) is not:

(58) John telephoned Mary during every meeting until Christmas,

(59) (?) John telephoned Mary during a meeting until Christmas.

However, it is clear that the universal quantification over meetings in (58) is already provided by the tPP during every meeting, and not (or not obviously) by the temporal preposition until. Therefore, we propose that until be assigned the same meaning as before:

(60) $[\![_{\text{tP}}$ until $]\!] = \lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))], I)],$

but that it be restricted to apply to universally quantified modificands. We can then derive, again, in the familiar way:

(61) $[\![_{\text{S}}$ John telephoned Mary during every meeting until Christmas $]\!] =$
$$\lambda I[\mathbf{the}(\lambda x_2[\text{CHRISTMAS}(x_2) \wedge \text{time}(x_2) \subseteq I],$$
$$\lambda y_1[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time-to}(I, \text{time}(y_1))],$$
$$\lambda y_0[\mathbf{a}(\lambda x_0[\text{TELEPHONE}(\text{JOHN}, \text{MARY})(x_0) \wedge$$
$$\text{time}(x_0) \subseteq \text{time}(y_0)],$$
$$\top)])])],$$

which is the correct truth-condition. (We assume a missing determiner contributing a **the** to $[\![_{\text{tNP}}$ Christmas$]\!]$.)

Clearly, there are many fine points regarding temporal prepositions that we could discuss at length. For an informal account, see Quirk *et al.* [17]. However, the main contribution of this paper is orthogonal to the details mentioned by these authors, and we need not recapitulate their observations here. We also mention in passing that, in the present paper, the issue of aspectal class (see Vendler [21], and for more recent work, Verkuyl [23], ter Meulen [20] or Steedman [18]) is largely ignored, even though it does bear importantly on temporal prepositions (as illustrated, for example, by the classic for/in test). An account of tPPs along the lines presented here in state-reporting sentences is worked out by the present authors in [16], but again, the details are not essential to the main thrust of this paper.

3 Discussion

Before proceeding with our detailed discussion of the semantics of tPPs, let us pause to take stock and justify some of the proposals made in the last session. Two simple observations drive most of what has been so far presented. The first is that, in the sentence:

(62) Mary kissed John during every meeting,

the universal quantification in the tPP during every meeting must scope over the existential quantification in its modificand Mary kissed John, because no single kiss can take place in several meetings. Indeed, the function of the tPP is to pick out a collection of intervals (in this case, the times of the meetings) within which the quantification in the modificand is then constrained. The significance of this observation lies in the variety of semantic object on which the tPP operates—namely, one in which the relevant object variable is already bound by quantification, and in which only the temporal context-variable is accessible to the tPP-meaning. The second observation concerns cascades of tPPs such as

(63) Mary kissed John during every meeting one Monday before Christmas,

where the function of each successive tPP is to pick out an interval or intervals to which previous quantification is restricted. The significance of this observation lies in the variety of semantic object which a tPP must produce, namely, an object essentially similar in form to an unmodified sentence, where the quantification introduced by the tPP is restricted to some variable temporal context.

There is, as we shall see, much more to be said about temporal aspects of sentence meanings and the way tPPs interact with them, but the phenomena of universally quantified tPPs and cascaded tPPs must at any rate be correctly handled. It comes as something of a surprise, therefore, to note that previous semantic accounts of tPPs experience difficulties with these phenomena. Consider, for example, the Dowty's account in [5], applied to the sentence

(64) Mary kissed John on Thursday.

According to Dowty, the tPP on Thursday contributes the meaning:

(65) $\lambda P[\exists I(I \subseteq \textsc{thursday} \wedge P(I))]$.

(Here, and in the sequel, we continue to use our notation, and again suppress information provided by the verb tense.) Dowty takes the underlying sentence Mary kissed John in (64) to quantify over time intervals rather than events. Specifically it contributes the meaning:

(66) $\lambda I[\textsc{kiss}(\textsc{mary}, \textsc{john})(I)]$.

And the tPP meaning then applies to the underlying sentence meaning to yield:

(67) $\exists I(I \subseteq \textsc{thursday} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(I))$.

Thus, on Dowty's account, (at least some) tPPs contribute existential quantification together with conditions which are conjoined with the basic description of an event contained in the unmodified sentence. Indeed it is clear from the fragment which Dowty presents that the existential quantification actually originates in the temporal preposition on. Thus, Dowty's account differs from that of the previous section, where tPPs apply to already-quantified sentence meanings and do not themselves contribute existential quantification scoping over the whole sentence.

Dowty's procedure suffers from the difficulty that a special rule is required to provide the existential quantification when no temporal adverbial is present. (Such a rule is not unlike like Bäuerle and Stechow's [3] assumption of a covert adverbial providing quantification when no overt quantifying adverbials are present). However, a more serious difficulty concerns quantifier scoping. Dowty's account works correctly when the tPP complement is determined by a or the (as in all of his examples), but tPP complements determined by every, as in sentence (62), would cause problems. Making reasonable assumptions about the interpretation of the phrase every meeting, the tPP during every meeting would then have to be

(68) $\lambda P[\exists I(\mathbf{every}(\lambda x[\textsc{meeting}(x)],$
$\lambda y[I \subseteq \mathrm{time}(y) \wedge P(I)]))]$,

with the existential quantification provided by the preposition during scoping over the universal quantification in its complement. This would yield, as the meaning of (62):

(69) $\exists I(\mathbf{every}(\lambda x[\textsc{meeting}(x)],$
$\lambda y[I \subseteq \mathrm{time}(y) \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(I)]))$.

And of course (69) is absurd when there are two or more non-overlapping meetings. Perhaps some form of quantifier raising might be used to rescue such cases, but it is unclear exactly what the details should be. Our account, by contrast, handles sentence (62) easily.

Similar problems beset Dowty's treatment of multiple tPPs. Although Dowty only sketches an account of how his proposed semantics should deal with such cases, it is clear that he requires the time over which the reported event occurs to satisfy a *conjunction* of conditions—one imposed by each tPP. It is instructive in this regard to consider the only example Dowty gives:

(70) I first met John Smith at two o' clock in the afternoon on a Thursday in the first week of June in 1942.

In *this* example, the time of meeting is indeed one which is (i) at a 2 o'clock in the afternoon, (ii) on a Thursday, (iii) in the first week of June and (iv) in 1942. But the fact that Dowty's account works here is entirely due to the absence of universal quantification in the tPP complements. If we consider instead sentence (63), then it no longer makes sense to regard the three tPPs as conjuncts: rather, the quantification in each tPP (except the last) is limited to the intervals identified by subsequent tPPs.

Stump [19] chapter III contains a detailed account of a wide range of tPPs (mostly, but not exclusively, having sentential complements), improving on Dowty's theory by taking tPPs to apply to 'temporal abstracts'—basically, unquantified sentence-meanings—with existential quantification being performed in a finalization operation. On this account, the tPP during the meeting contributes the meaning:

(71) $\lambda P \lambda I[\mathbf{the}(\lambda x[\textsc{meeting}(x)], \lambda y[I \subseteq \text{time}(y) \wedge P(I)])]$.

The sentence Mary kissed John contributes the meaning:

(72) $\lambda I[\textsc{kiss}(\textsc{mary}, \textsc{john})(I)]$.

And the tPP meaning then applies to the underlying sentence meaning to yield:

(73) $\lambda I[\mathbf{the}(\lambda x[\textsc{meeting}(x)],$
$\lambda y[I \subseteq \text{time}(y) \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(I)])]$,

which, when finalized by existential quantification, yields the correct meaning. More recently, Ogihara [13] has proposed a semantic theory along similar lines. Ogihara is, however, primarily concerned with issues of tense, and does not focus especially on tPPs. We note in passing that, in the earlier paper [11], Ogihara asserts that final existential quantification is contributed—along with restrictions to past times—by the tense phrase, but we shall not pause to discuss this assertion here.

Like Dowty, however, Stump and Ogihara still take tPPs to contribute extra conditions which are *conjoined* to the main event predicate contributed by the matrix clause; and to form such conjuctions, the tPP must have access to the variable I indicating the main event reported by the sentence. This fact causes problems in examples such as (62), where the tPP complement introduces universal quantification. For the temporal abstract

(74) $\lambda I[\mathbf{every}(\lambda x[\textsc{meeting}(x)],$

$$\lambda y[I \subseteq \text{time}(y) \wedge \text{KISS}(\text{MARY}, \text{JOHN})(I)])].$$

is satisfied by no values of I when there are two or more non-overlapping meetings, and its existential finalization is again absurd.

The approach presented in the previous section avoids these problems through the use of temporal context variables. Thus, we follow Stump in taking sentence meanings to be temporal abstracts, with lambda-abstracted variables available for binding by tPPs. However, on our account, these variables are *temporal context variables*, indicating intervals within which the events reported by the sentence must occur; the object variables themselves—those corresponding to the actual events the sentence is about—are quantified at the point when any tPPs apply, and are not visible to those tPPs.

To be sure, we are not the first to have considered tPPs with universally quantified complements. Kamp and Reyle, who discuss the semantics of tPPs within the context of discourse representation theory ([10] chapter 5), do consider such examples, always giving the correct quantifier scoping. Unfortunately, although they provide detailed truth-conditions for a range of sentences involving tPPs, we are not told enough to understand precisely how this correct scoping is determined. In particular, the quantification introduced by tPPs sometimes scopes above the main sentence quantification (e.g. in the discourse representation structure of p. 613) and sometimes below it (e.g. in the the discourse representation structure of p. 636). Perhaps Kamp and Reyle have an explanation for this behaviour; if so we are unaware of it, and cannot determine if it is a simpler or more natural account than ours. Certainly, it is unclear how they propose to treat the examples discussed below where, as we shall see, the issue of what sorts of meanings tPPs modify starts to get more complicated.

Another system where universally quantified tPP complements are covered is Hwang and Schubert [9], which considers examples such as every spring and every Saturday. Hwang and Schubert's system is so complicated that it is difficult to compare with the present account. However, it appears that their correct handling of these cases relies on a special rule introducing collections of events in response to universally quantified tPP complements (see the last two grammar rules on p. 253). In this respect, we claim, the approach taken here is more uniform, though we do concede that Hwang and Schubert aim at far greater coverage. Various other fully implemented systems reported in the AI literature also handle temporal prepositions as part of a wider coverage of English, for example Alshawi [1], Crouch and Pullman [4].

Ogihara [11] gives examples of sentences involving universal quantification with the temporal preposition when, translating, for example, the sentence, When stresed, Mary always watched TV into the formula

(75) $\exists I'(I' \leq \text{NOW} \wedge \forall I(\text{STRESSED}(\text{MARY})(I) \wedge I \subseteq I' \rightarrow$

$$\text{WATCH}(\text{MARY}, \text{TV})(I))).$$

However, all of these universally quantified examples involve matrix clauses describing states or processes (as opposed to events), in which existential quantification is absent, so that the scoping problems mentioned above do not arise. It does seem that Ogihara would have to resort to some form of quantifier rescoping for event-reporting sentences.

So far in this section, we have justified our use of temporal context variables in sentence meanings, and hence in tPP meanings, leading to our descision to take tPP meanings to be tGQs. But earlier, we proposed that the meanings of tNPs occurring as tPP *complements* should also contain context variables—thus turning them into tGQs as well. What is the justification for this proposal?

Consider the tPPs:

(76) $[\![_{\text{tPP}}\textsf{during every meeting}]\!] =$
$\lambda P \lambda I[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])]$.

(77) $[\![_{\text{tPP}}\textsf{during a meeting}]\!] =$
$\lambda P \lambda I[\mathbf{a}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])]$.

Now the meanings of every meeting and a meeting are standardly taken to be the generalized quantifiers:

(78) $\lambda P[\mathbf{every}(\lambda x[\text{MEETING}(x)], P)]$

(79) $\lambda P[\mathbf{a}(\lambda x[\text{MEETING}(x)], P)]$.

But on this view, the semantic effect of during would have to induce the mappings:

(80) $\lambda P[\mathbf{every}(\lambda x[\text{MEETING}(x)], P)] \mapsto$
$\lambda P \lambda I[\mathbf{every}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])]$

(81) $\lambda P[\mathbf{a}(\lambda x[\text{MEETING}(x)], P)] \mapsto$
$\lambda P \lambda I[\mathbf{a}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])]$,

and such a map is not in general well-defined! For example, if it happens that there is exactly one meeting in the universe of discourse, then the expressions on left-hand side of $\mapsto$ become equal, but the expressions on the right-hand side will in general be different. (To see this, choose a value of I such that there are no meetings within I.) This conclusion leaves us in the awkward position of having to say that the meaning of during is noncompositional, in that the meanings of the tPPs it forms are not a function of the meanings of their complements. This is a conclusion we want to avoid.

Various possibilities present themselves. One would be to abandon the basically Montagovian framework we have been using and to assume that the semantics of during really does have access to the internal structure of (78) and (79). That is, we take these meanings to be, in effect, *strings of symbols*, which are then later interpreted using ordinary model theoretic semantics. Alternatively, we could remain within a Montagovian framework but interpret (78) and (79) *intensionally*, in effect introducing an extra variable w representing the possible world at which these meanings are to be evaluated. For, while the meanings of every meeting and one meeting may be identical in one possible world, they are not identical in all possible worlds, so perhaps the functionality of the semantic effect of during could be preserved after all.

Neither solution is particularly appealing, however: the first amounts to abandoning a widely, though admittedly not universally, accepted approach to semantics; the second requires us to make the implausible assumption that temporal prepositions are modal in character; both are likely to involve a messy fight with the formalism when we come to work out the details. Much better that we suppose the temporal context variable I to be part of the meanings of the tPP complements. This supposition seems to be the most natural solution to the fact that the quantifier introduced by noun-phrase complements of tPPs must scope over the restriction to the temporal context in question. And, as we saw in the previous section, once we have decided to take tNP meanings to be tGQs, the resulting derivations give the appropriate tPP meanings.

4 tPPs and unquantified modificands

So far, we have argued that, in order to get the required quantifier scoping in examples such as:

(82) Mary kissed John during every meeting,

the tPP during every meeting must modify the existentially quantified meaning of Mary kissed John, and should thus take the form of the tGQ:

(83) $[\![_{\mathrm{tPP}}\text{during every meeting}]\!] =$
$\lambda P \lambda I[\mathbf{every}(\lambda x_1[\textsc{meeting}(x_1) \wedge \mathrm{time}(x_1) \subseteq I], \lambda y_0[P(\mathrm{time}(y_0))])]$.

We drew attention to the variety of semantic object on which the tPP operates—namely, one in which the event-carrying variable is already bound by quantification, and in which only the temporal context variable is accessible to the tPP meaning. However, other more complicated examples suggest that tPPs should modify other kinds of meanings. The job of this section is to investigate these cases.

We begin with an example. Consider:

(84) Mary kissed John during every meeting on a Monday,

which contains two temporal prepositions. The most natural reading of (84) states that Mary kissed John during every meeting on *any* Monday (within the relevant temporal context). Moreover, it is plausible that, on this reading, the tPP on Monday attaches to the noun meeting rather than to the sentence, thus:

(85) Mary kissed John $[_{\mathrm{tPP}}$ during $[_{\mathrm{tNP}}$ every $[_{\mathrm{tN'}}$ meeting $[_{\mathrm{tPP}}$ on a Monday]]]].

Since we have not yet encountered tPPs attaching to tNs, we must explain how they function in this capacity; specifically, we must account for the meaning of (85).

Let us first get a clearer idea of the problem. According to our proposals, the tPP on a Monday means:

(86) $[\![_{\mathrm{tPP}}\text{on a Monday}]\!] =$
$\lambda P \lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])]$,

and the tN meeting means:

(87) $[\![_{\mathrm{tN}}\text{meeting}]\!] = \lambda x_1 \lambda I'[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I']$.

Now we would like (86) somehow to apply to (87); but of course we have a type mismatch. That such a type mismatch should arise is not surprising, bearing in mind the fact that we have so far considered examples such as sentence (82), where scoping considerations mean that the tPP argument must modify a meaning which already quantifies over events. In the present example, however, the meaning of meeting contains no quantifier.

In (87), we have two variables, an object variable x_1 and a temporal context variable I'. Now, just as with sentences, so too with temporal nouns, we can regard the tPP on a Monday as operating only the temporal context variable, leaving the object variable alone. Informally, then, we propose proceeding as follows. First, let us 'suspend' the troublesome object variable x_1:

(88) $\lambda I'[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I']$.

Now (88) is of the right type for application of (86), and we have:

(89) $\lambda P \lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])]($
$\lambda I'[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I']) =$
$\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])]$.

Now let us 'restore' the suspended λx_1:

(90) $[\![_{\mathrm{tN'}}\text{meeting on a Monday}]\!] =$
$\lambda x_1 \lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])]$.

Before making this derivation formally respectable, let us assess the plausibility of the resulting meaning-assignment (90). Just as the assigned meaning in (87) is the relation holding between an event x_1 and an interval I' just in case x_1 is a meeting contained within I', so the assigned meaning in (90) is the relation holding between an event x_1 and an interval I just in case x_1 is a meeting contained within some Monday or other contained within I. Moreover, (90) yields the correct meanings for sentences such as (85). Proceeding exactly as before, we have:

(91) $[\![_{\mathrm{tNP}}\textsf{every meeting on a Monday}]\!] =$
$[\![_{\mathrm{Det}}\textsf{every}]\!](_1[\![_{\mathrm{tN'}}\textsf{meeting on a Monday}]\!])_1 =$
$\lambda P\lambda I[\mathbf{every}(\lambda x_1[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$
$P)].$

(92) $[\![_{\mathrm{tPP}}\textsf{during every meeting on a Monday}]\!] =$
$[\![_{\mathrm{tP}}\textsf{during}]\!]([\![_{\mathrm{tNP}}\textsf{every meeting on a Monday}]\!]) =$
$\lambda P\lambda I[\mathbf{every}(\lambda x_1[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$
$\lambda y_0[P(\text{time}(y_0))])].$

(93) $[\![_{\mathrm{S}}\textsf{Mary kissed John during every meeting on a Monday}]\!] =$
$[\![_{\mathrm{tPP}}\textsf{during every meeting on a Monday}]\!]([\![_{\mathrm{S}}\textsf{Mary kissed John}]\!]) =$
$\lambda I[\mathbf{every}(\lambda x_1[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY},\text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)], \top)])].$

To complete our analysis of sentence (85), it remains only to make rigorous the informal derivation in (88)–(90). Let the variable u have any type τ, and the viariable P, type $(\tau, \mathbf{t})$. Let the viariable x have any type. (Thus, given objects $\lambda P[\psi(P)]$ and $\lambda x\lambda u[\phi(x,u)]$, the former is prevented from applying to the latter by the interposed λx.) We define our second form of pseudo-application of $\lambda P[\psi(P)]$ to $\lambda x\lambda u[\phi(x,u)]$ (promised earlier in the paper) by:

(94) $$\lambda P[\psi(P)](_2\lambda x\lambda u[\phi(x,u)])_2 =_{\mathrm{Def}} \lambda x[\lambda P[\psi(P)](\lambda u[\phi(x,u)])] = \lambda x[\psi(\lambda u[\phi(x,u)])].$$

Although definition (94) may look confusing, it is just a formalization of the steps carried out in (88)–(90). Using this notation, we can express the mechanism for combining a tPP meaning with a tN meaning as:

(95) $[\![_{\mathrm{tN'}}\textsf{meeting on a Monday}]\!] = [\![_{\mathrm{tPP}}\textsf{on a Monday}]\!](_2[\![_{\mathrm{tN}}\textsf{meeting}]\!])_2.$

It is then routine to compute, on the basis of (86) and (87):

(96) $[\![_{\mathrm{tN'}}\textsf{meeting on a Monday}]\!] =$
$\lambda P\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])](_2$
$\lambda x_1\lambda I'[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I'])_2 =$
$\lambda x_1[\lambda P\lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])]($
$\lambda I'[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I'])] =$

$$\lambda x_1 \lambda I[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$$

as required.

We conclude this section with a demonstration of the power of the semantics developed so far. The sentence

(97) Mary kissed John before the meeting on Monday

has two phrase-structures, namely:

(98) Mary kissed John
$[_{\text{tPP}}$ before $[_{\text{tNP}}$ the meeting $]]$ $[_{\text{tPP}}$ on $[_{\text{tNP}}$ Monday $]]$

(99) Mary kissed John
$[_{\text{tPP}}$ before $[_{\text{tNP}}$ the $[_{\text{tN}'}$ meeting $[_{\text{tPP}}$ on $[_{\text{tNP}}$ Monday $]]]]]$.

Before we actually derive any meanings for (97), let us establish what the result ought to be. For the sake of simplicity, let before be understood in the sense of "any time before", and suppose that the overall temporal context for the sentence is an interval I (where I lies before the utterance time)—say, starting at dawn on Sunday and finishing at dusk the following Saturday. At what times must Mary kiss John for this sentence to be true? There seem to be two possible answers: (i) any time from the start of the Monday until the meeting that day, and (ii) any time from dawn on Sunday (i.e. the start of the temporal context) until the meeting on Monday. Let us call these two readings of (97) the 'short' and 'long' meanings, respectively. There are good reasons to suppose that the short meaning belongs to phrase structure (98) and the long meaning to phrase structure (99). For example, we notice that preposing the tPP on Monday—forcing a phrase structure akin to (98)—causes the long reading to vanish. Conversely, tPP complements involving of, such as until Thursday of week 3—which must have the same phrase structure as (99)—do not admit the short reading. Our task is to show how the correct meanings can be generated.

First, we consider (98): the derivation in this case follows exactly the path laid out in section 2. The meaning of the tPP before the meeting is:

(100) $[\![_{\text{tPP}}\text{before the meeting}]\!] =$
$$\lambda P \lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))])].$$

The meaning of the tPP on Monday is:

(101) $[\![_{\text{tPP}}\text{on Monday}]\!] =$
$$\lambda P \lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])].$$

The sentence meaning is:

(102) $[\![_{\text{S}}\text{Mary kissed John}]\!] =$

$\lambda I[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq I], \top)]$.

Pseudo-applying the tGQs (100) and (101) in the only sensible order yields:

(103) $[\![_{\text{S}}\textsf{Mary kissed John before the meeting on Monday}]\!] =$
$$\lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)], \lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time-to}(\text{time}(y_1), \text{time}(y_0))], \top)])])],$$

which is the short meaning, as required.

Next we come to the phrase-structure (99). Proceeding by analogy with our earlier treatment, we have:

(104) $[\![_{\text{tN}'}\textsf{meeting on Monday}]\!] = [\![_{\text{tPP}}\textsf{on Monday}]\!]({}_2[\![_{\text{tN}}\textsf{meeting}]\!])_2 =$
$$\lambda P \lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])]({}_2 \lambda x_1 \lambda I'[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I'])_2 =$$
$$\lambda x_1 \lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])].$$

Then the derivation (91)—(93) can be mirrored here:

(105) $[\![_{\text{tNP}}\textsf{the meeting on Monday}]\!] =$
$$[\![_{\text{Det}}\textsf{the}]\!]({}_1[\![_{\text{tN}'}\textsf{meeting on Monday}]\!])_1 =$$
$$\lambda P \lambda I[\mathbf{the}(\lambda x_1[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])], P)].$$

(106) $[\![_{\text{tPP}}\textsf{before the meeting on Monday}]\!] =$
$$[\![_{\text{tP}}\textsf{before}]\!]([\![_{\text{tNP}}\textsf{the meeting on Monday}]\!]) =$$
$$\lambda P \lambda I[\mathbf{the}(\lambda x_1[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])], \lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))])].$$

(107) $[\![_{\text{S}}\textsf{Mary kissed John before the meeting on Monday}]\!] =$
$$[\![_{\text{tPP}}\textsf{before the meeting on Monday}]\!]([\![_{\text{S}}\textsf{Mary kissed John}]\!]) =$$
$$\lambda I[\mathbf{the}(\lambda x_1[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])], \lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time-to}(I, \text{time}(y_0))], \top)])],$$

which is the long meaning, as required.

5 Sentence meanings and tGQs

5.1 Sentential tPP complements

Some temporal prepositions take both sentential and noun-phrase complements:

(108) Jane kissed John before the meeting,

(109) Jane kissed John before Mary arrived.

Just as sentence (108) locates Jane's kissing John with respect to an event picked out by the noun phrase the meeting, sentence (109) does so with respect to one picked out by the sentence Mary arrived. Ideally, we would like to assign the same meaning to before in both cases, which suggests that we should assign meanings of the same form to tPP complements, regardless of whether those complements are sentences or noun phrases. Can we do this?

The answer is: yes, provided we complicate sentence meanings slightly. According to the framework adopted so far, we have

(110) $[\![_{\mathrm{S}}\text{Mary arrived}]\!] =$
$\lambda I[\mathbf{a}(\lambda x_1[\textsc{arrive}(\textsc{mary})(x_1) \wedge \mathrm{time}(x_1) \subseteq I], \top)]$.

For a given value of I—that is, for a given temporal context—this meaning simply makes a statement, something true or false. Notice the similarity in form between (110) and the noun-phrase meaning assignment:

(111) $[\![\text{a meeting}]\!] =$
$\lambda P \lambda I[\mathbf{a}(\lambda x[\textsc{meeting}(x) \wedge \mathrm{time}(x) \subseteq I], P)]$.

Indeed, if we replace the trivial predicate $\top$ in (110) by a lambda-abstracted variable P of type $(\mathbf{e}, \mathbf{t})$, thus:

(112) $\lambda P \lambda I[\mathbf{a}(\lambda x_1[\textsc{arrive}(\textsc{mary})(x_1) \wedge \mathrm{time}(x_1) \subseteq I], P)]$,

the similarity of form is complete. We need just one more modification before we can deal with sentential tPP complements. In (112), the second-order relation is **a**, reflecting our assumption that event-reporting sentences existentially quantify. As we will see, however, it is usually better to take the quantification in subordinate clauses to be either definite or universal. Therefore, we propose that the **a** in (112) be replaced by a schematic quantifier **Q**, thus:

(113) $[\![_{\mathrm{S}_1}\text{Mary arrived}]\!] =$
$\lambda P \lambda I[\mathbf{Q}(\lambda x_1[\textsc{arrive}(\textsc{mary})(x_1) \wedge \mathrm{time}(x_1) \subseteq I], P)]$.

This is our final and most general form for the meaning of an event-reporting sentence. We use the symbol S_1 to indicate items of this category; S meanings as introduced above can then be seen as a finalized form of S_1 meanings, with the variable P set to $\top$. Thus, on the present account, S_1 meanings are tGQs, just as tNP and tPP meanings are.

Now that S_1 meanings are in the same form as tNP meanings, derivation of meanings for sentences such as (109) proceeds identically as for sentence (108), given the reasonable assumption that the temporal preposition before selects $\mathbf{Q} = \mathbf{the}$. That is:

(114) $[\![_{\text{tPP}}\text{before Mary arrived}]\!] = [\![_{\text{tP}}\text{before}]\!]([\![_{S_1}\text{Mary arrived}]\!]) =$
$\lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))], I)]($
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq I], P)]) =$
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))])],$

(115) $[\![_S$ Jane kissed John before Mary arrived $]\!] =$
$[\![_{\text{tPP}}$ before Mary arrived $]\!]([\![_S$ Jane kissed John $]\!]) =$
$\lambda I[\mathbf{the}(\lambda x_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{JANE}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time-to}(I, \text{time}(y_0))],$
$\top)])].$

Thus, our decision to treat S_1 meanings as tGQs gives us a straightforward account of pairs of sentences such as (108) and (109).

Now initially, it seems that we have paid a heavy price for this uniform treatment of sentential and noun-phrase tPP complements, because we have been led to distinguish between sentences which are *complements* of tPPs—which we take to have S_1 meanings—and sentences which are *modificands* of tPPs—which we take to have S meanings. And this seems inelegant. We shall see in the next section how to overcome this difficulty.

5.2 Modified sentential tPP complements

However, the similarity between sentential and noun-phrase tPP complements does not end there. Consider

(116) Jane kissed John before the meeting on Monday,

(117) Jane kissed John before Mary arrived on Monday.

We saw in section 4 that sentence (116) has long and short meanings; and of course exactly the same ought to hold for sentence (117). The short meaning, in which before Mary arrived and on Monday are treated as separate tPPs, presents no problem; the above proposals yield:

(118) $[\![_S\text{Jane kissed John before Mary arrived on Monday}]\!] =$
$\lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\mathbf{the}(\lambda x_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)],$

$$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{JANE}, \text{JOHN})(x_0) \wedge \\ \quad \text{time}(x_0) \subseteq \text{time-to}(\text{time}(y_1), \text{time}(y_0))], \\ \top)])])].$$

But how are we to generate the long meaning for (117)? The details of the answer are instructive.

Recall that, in deriving the short meaning of sentence (116) we first applied the tPP meaning on Monday to the *undetermined* meaning of meeting, in (104), and then applied the determiner meaning the, in (105). We stressed that the tPP on Monday had to apply to an unquantified meaning, leaving the event-variable x_1 available for binding by a higher-scoping determiner. Exactly similar considerations now apply to sentence (117). We want the tPP complement Mary arrived to contribute an *undeteremined* meaning of the form:

(119) $[\![_{S_2}\text{Mary arrived}]\!] = \lambda x_1 \lambda I'[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq I']$,

to which the tPP on Monday is applied, by exact analogy with derivation (104):

(120) $[\![_{S_2}\text{Mary arrived on Monday}]\!] = [\![_{tPP}\text{on Monday}]\!]({}_2[\![_{S_2}\text{Mary arrived}]\!])_2 =$
$\lambda P \lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[P(\text{time}(y_1))])]({}_2$
$\lambda x_1 \lambda I'[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq I'])_2 =$
$\lambda x_1 \lambda I[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])]$.

We now proceed by analogy with tNPs. Recall that a tNP meaning is obtained from a tN meaning by pseudoapplying (using $({}_1 \ldots)_1$) a determiner meaning of the form $\lambda Q \lambda P[\mathbf{Q}(Q, P)]$. Likewise, we propose that an S_1 meaning be obtained from an S_2 meaning by pseudoapplication of a schematic sentence determiner, specifically:

(121) $[\![_{S_1}\text{Mary arrived on Monday}]\!] =$
$\lambda Q \lambda P[\mathbf{Q}(Q, P)]({}_1[\![_{S_2}\text{Mary arrived on Monday}]\!])_1$.

Simple calculation shows:

(122) $[\![_{S_1}\text{Mary arrived on Monday}]\!] =$
$\lambda P \lambda I[\mathbf{Q}(\lambda x_1[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$
$P)]$,

as required.

At this point, the meaning of the tPP complement Mary arrived on Monday has the familiar form of a tGQ, and the derivation of the long meaning proceeds exactly as before. Taking the temporal preposition before to select $\mathbf{Q} = \mathbf{the}$ again, the foregoing proposals yield:

(123) $[\![_{\text{tPP}}\textsf{before Mary arrived on Monday}]\!] =$
$[\![_{\text{tP}}\textsf{before}]\!]([\![_{\text{S}_1}\textsf{Mary arrived on Monday}]\!]) =$
$\lambda P\lambda I[\mathbf{the}(\lambda x_1[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$
$\lambda y_0[P(\text{time-to}(I, \text{time}(y_0)))])],$

(124) $[\![_{\text{S}}\textsf{Jane kissed John before Mary arrived on Monday}]\!] =$
$[\![_{\text{tPP}}\textsf{before Mary arrived on Monday}]\!]([\![_{\text{S}}\textsf{Jane kissed John }]\!]) =$
$\lambda I[\mathbf{the}(\lambda x_1[\mathbf{the}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I],$
$\lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{JANE}, \text{JOHN})(x_0)\wedge$
$\text{time}(x_0) \subseteq \text{time-to}(I, \text{time}(y_0))],$
$\top)])].$

This example provides evidence that we should recognise two forms of sentence-meanings: determined and undetermined. We are already familiar with determined sentence meanings, which have the form of tGQs. As such, they already contain a quantifier which binds the main event variable, thus rendering it inaccessible to subsequent binding. We argued at the very beginning of this paper that it must be possible for a tPP to apply to a determined sentence meaning, in order to get correct quantifier scoping with tPPs such as during every meeting. Undetermined sentence meanings were first encountered in this section. They have the same form as temporal nouns, and, as such, make an object variable available for future binding. We have just argued that it must be possible for a tPP to apply to an undetermined sentence meaning, so that subsequent determination scopes over it.

An even more convincing illustration of the need to distinguish these two types of sentence meanings is provided by whenever. On the account developed here, we may take whenever to have the same meaning as during, at and on, namely:

(125) $[\![_{\text{tP}}\textsf{whenever}]\!] = \lambda\mathcal{P}\lambda P\lambda I[\mathcal{P}(\lambda y_0[P(\text{time}(y_0))], I)].$

However, we propose that whenever has the peculiarity that it requires a sentential complement, and selects $\mathbf{Q} = \mathbf{every}$ in that complement. It is then easy to derive, for example:

(126) $[\![_{\text{S}}\textsf{Jane telephoned John whenever Mary arrived}]\!] =$
$\lambda I[\mathbf{every}(\lambda x_1[\text{ARRIVE}(\text{MARY})(x_1)\wedge\text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{TELEPHONE}(\text{JANE}, \text{JOHN})(x_0)\wedge$
$\text{time}(x_0) \subseteq \text{time}(y_0)],$
$\top)])].$

Some readers may object to the strict inclusion here: typically Jane can be expected to have telephoned John just after each arrival by Mary. However, we do not propose to discuss the complexities of the temporal relationships involved in when- and whenever-clauses (see, e.g. Hinrichs [7]). Rather, we assume that the tPP complement in this case picks out somewhat extended intervals around Mary's actual arrival times, and within which the matrix-clause events are asserted to occur. (This approach to when and whenever is quite standard.)

As a final illustration of the above account, consider the sentence

(127) Jane telephoned John whenever Mary arrived on a Monday,

understood in such a way that the universal quantification ranges over all occasions when Mary arrived on *any* Monday within the temporal context under discussion. (Syntactically, this is the reading where on a Monday attaches to Mary arrived.) By an analogous derivation as for (122), we obtain:

(128) $[\![_{S_1}\text{Mary arrived on a Monday}]\!] =$
$$\lambda P \lambda I[\mathbf{Q}(\lambda x_1[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])], P)].$$

Remembering that whenever selects $\mathbf{Q} = \mathbf{every}$, we have

(129) $[\![_{tPP}\text{whenever Mary arrived on a Monday}]\!] =$
$$[\![_{tP}\text{whenever}]\!]([\![_{S_1}\text{Mary arrived on a Monday}]\!]) =$$
$$\lambda P \lambda I[\mathbf{every}(\lambda x_1[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])], \lambda y_0[P(\text{time}(y_0))])].$$

Whence:

(130) $[\![_{S}\text{Jane telephoned John whenever Mary arrived on a Monday}]]\!] =$
$$\lambda I[\mathbf{every}(\lambda x_1[\mathbf{a}(\lambda x_2[\text{MONDAY}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\text{ARRIVE}(\text{MARY})(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)])], \lambda y_0[\mathbf{a}(\lambda x_0[\text{TELEPHONE}(\text{JANE}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)], \top)])].$$

In this case, it is particularly clear that the tPP on a Monday should apply *before* determination of Mary arrived, since determination results in universal quantification of the object variable x_1.

6 Determined and undetermined modificands

At this point, all key elements of our account of tPP meanings are in place. To be sure, there are many matters of detail that we have not discussed at all, but these issues are best left for another time. However, we still need to tidy up one or two general issues before our account is complete; and doing so will afford us a better overview of the preceding mass of detail.

We consider first the status of sentence meanings. So far we have encountered three types of sentence meaning: finalized sentence meanings, which we refer to as S meanings, and their determined and undetermined semantic precursors, S_1 meanings and S_2 meanings. We argued in the last section that distinguishing S_1 meanings and S_2 meanings allows us to account neatly for various scoping phenomena involving tPPs. It is time to take another look at S meanings in the light of these arguments.

So far in this paper, we have suggested that, when tPPs modify sentences, they apply to finalized sentence meanings, that is, to S meanings. Indeed, given that tPP meanings are tGQs and hence of type $((\mathbf{e},\mathbf{t}),(\mathbf{i},\mathbf{t}))$, they can only apply to items of type $(\mathbf{e},\mathbf{t})$, and thus not to other tGQs. And this state of affairs might be thought inelegant. For one thing, sentential complements of tPPs now have a different form to sentences in main clauses. Furthermore, we have to suppose that when tPPs modify a sentence, the finalization operation (i.e. conversion from tGQ) occurs *before* modification by temporal adverbials. As we have seen from our discussions of Stump and Ogihara, ours is not the only account to suppose a finalization process; but it does seem odd to apply such a process before temporal adverbials have been combined (even if it is called something other than 'finalization').

In fact, however, we have already encountered enough machinery to avoid this problem if we want. Instead of taking tPPs to *apply* to their modificands, we can instead take them to *pseudoapply* (using $(_2\ldots)_2$) to them. That is, we have:

(131) $[\![_{S_1}\textsf{Mary kissed John}]\!] =$
$\lambda P\lambda I[\mathbf{a}(\lambda x_0[\textsc{kiss}(\textsc{mary},\textsc{john})(x_0)\wedge\text{time}(x_0) \subseteq I], P)]$,

and we now propose

(132) $[\![_{S_1}\textsf{Mary kissed John during every meeting}]\!] =$
$[\![_{tPP}\textsf{during every meeting}]\!](_2[\![_{S_1}\textsf{Mary kissed John}]\!])_2$.

It is then simple to compute:

(133) $[\![_{S_1}\textsf{Mary kissed John during every meeting}]\!] =$
$\lambda P\lambda I[\mathbf{every}(\lambda x_1[\textsc{meeting}(x_1)\wedge\text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\textsc{kiss}(\textsc{mary},\textsc{john})(x_0)\wedge\text{time}(x_0) \subseteq \text{time}(y_0)], P)])]$.

(We have set $\mathbf{Q} = \mathbf{a}$ because we are dealing with a main clause.) Then we can apply finalization at the very end, to obtain the same S meaning as before.

Notice the work being done by pseudoapplication here: the abstracted variable λP in the S_1 meaning is protected, and only the following λI is used in the calculation. This is exactly as it was when we pseudoapplied tPP meanings to S_2 meanings, for example in (120): there, the abstracted variable λx_1 in the S_2 meaning was protected, and only the following $\lambda I'$ used in the calculation. The point about pseudoapplication is that it does not care about the type of the protected variable. That is why the process works on both determined and undetermined sentence meanings. Thus, the forgoing observations suggest the following derivation pattern for main clauses:

$$\text{determination} \rightarrow \text{tPP-modification} \rightarrow \text{finalization.}$$

Remember: tPP modification is allowed to apply after determination to handle tPP complements with universal quantification.

Actually, however, when the quantification in the tPP complements is existential or definite, there is no harm in allowing tPP modification to occur before determination—even in main clauses. Consider, for example:

(134) Mary kissed John during the meeting.

The familiar pattern of derivation—determination first, then tPP modification—gives us:

(135) $[\![_{S_1}\text{Mary kissed John during the meeting}]\!] =$
$\lambda P \lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\mathbf{a}(\lambda x_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)], P)])].$

However, there is no particular reason not to apply tPP modification first, deriving:

(136) $[\![_{S_2}\text{Mary kissed John during the meeting}]\!] =$
$[\![_{tPP}\text{during the meeting}]\!](_2[\![_{S_2}\text{Mary kissed John}]\!])_2 =$
$\lambda x_0 \lambda I[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)])],$

and then to apply determination (again taking $\mathbf{Q} = \mathbf{a}$):

(137) $[\![_{S_1}\text{Mary kissed John during the meeting}]\!] =$
$\lambda P \lambda I[\mathbf{a}(\lambda x_0[\mathbf{the}(\lambda x_1[\text{MEETING}(x_1) \wedge \text{time}(x_1) \subseteq I],$
$\lambda y_0[\text{KISS}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)])],$
$P)].$

Of course meaning (137) is logically equivalent to meaning (135).

So, applying tPPs before determination is sometimes harmless in main clauses, and is, as we argued in section 4, needed anyhow in sentential tPP complements. Therefore, we propose that tPP modification can occur both before and after determination. True, our semantic theory will then be allowed to generate absurd meanings with impossible quantifier scopings. But there are good general reasons to suppose that it is not the job of a semantic theory to avoid meanings which can be rejected as impossible on pragmatic grounds, given sufficient commonsense knowledge. That is, the reason for not hearing Mary kissed John during every meeting as stating that there is a single event of Mary's kissing John taking place in every one of a (usually temporally disjoint) set of meetings is simply that this reading is absurd; its rejection then follows on Gricean principles. Hence, what is important is that our semantic theory can generate the non-absurd quantifier scopings that we do hear. And we have shown through various examples that if tPP modifaction is allowed to apply to both S_1 and S_2 meanings, these correct quantifier scopings indeed result.

The picture of sentence meanings that emerges then is as follows. Initially, the verb and its complements combine to produce an (undetermined) S_2 meaning. This undetermined meaning can be modified by pseudoapplication of tPP meanings. At some stage, the S_2 meaning is determined to produce an S_1 meaning. This S_1 meaning can also be modified by pseudoapplication of tPP meanings. Finally (if this is important), the S_1 meaning can be converted into an S meaning to recover a more intuitive object to represent the meaning of the original sentence. We might diagram this process as follows:

$$\text{tPP-modification} \rightarrow \text{determination} \rightarrow \text{tPP-modification} \rightarrow \text{finalization.}$$

We have seen from examples that when tPPs modify sentences, they must be allowed to apply both before and after sentence-determination. We have also seen how tPPs must be allowed to modify temporal nouns before determination. Question: are there examples where tPPs modify temporal nouns after determination—that is, where tPPs modify tNPs?

It is difficult to find convincing examples here, but the best chance seems to come from of, which can arguably function as a temporal preposition in examples such as:

(138) Mary telephoned John on Monday of every week.

The preposition of always attaches to noun phrases and not to verb phrases. Yet it is clear that the universal quantification over weeks must scope over the (implicit) definite quantification over Mondays. We proceed as follows. Assuming an implicit definite article as before:

(139) $[\![_{\mathrm{tNP}}\textsf{(the) Monday}]\!] = \lambda P \lambda I[\mathbf{the}(\lambda x[\textsc{monday}(x) \wedge \mathrm{time}(x) \subseteq I], P)]$,

and taking of to have the same meaning as during, we have:

(140) $[\![_{\mathrm{tPP}}\textsf{of every week}]\!] =$

$$\lambda P \lambda I[\mathbf{every}(\lambda x_1[\text{WEEK}(x_1) \wedge \text{time}(x_1) \subseteq I], \lambda y_0[P(\text{time}(y_0))])].$$

Now we propose:

(141) $[\![_{\text{tNP}}$(the) Monday of every week$]\!] =$
$$[\![_{\text{tPP}}\text{of every week}]\!](_2[\![_{\text{tNP}}\text{(the) Monday}]\!])_2 =$$
$$\lambda P \lambda I[\mathbf{every}(\lambda x_2[\text{WEEK}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\mathbf{the}(\lambda x_1[\text{MONDAY}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)], P)])].$$

Proceeding as before and finalizing then gives us:

(142) $[\![_{\text{S}}$Mary telephoned John on (the) Monday of every week$]\!] =$
$$\lambda I[\mathbf{every}(\lambda x_2[\text{WEEK}(x_2) \wedge \text{time}(x_2) \subseteq I], \lambda y_1[\mathbf{the}(\lambda x_1[\text{MONDAY}(x_1) \wedge \text{time}(x_1) \subseteq \text{time}(y_1)], \lambda y_0[\mathbf{a}(\lambda x_0[\text{TELEPHONE}(\text{MARY}, \text{JOHN})(x_0) \wedge \text{time}(x_0) \subseteq \text{time}(y_0)], \top)])])].$$

This is the required quantifier scoping. It is clear that trying to apply the tPP of every week to the temporal noun Monday before determination would result in an absurd translation.

Thus, if we wish to treat of as a tPP, and give it the meaning proposed above, the situation with tPP modification of temporal noun phrases parallels that with tPP modification of sentences: tPPs must be allowed to apply both before and after determination to yield correct quantifier scoping. And again, the mechanism of pseudoapplication makes this possible. Thus, the picture that emerges of the derivation of tNP meanings is, exactly as for sentences (but ignoring the finalization, of course):

$$\text{tPP-modification} \rightarrow \text{determination} \rightarrow \text{tPP-modification}.$$

7 Conclusion

The primary aim of this paper was to account for the quantificational behaviour of tPPs in a variety of English sentences. In particular, we considered sentences and noun phrases both as tPP complements and as tPP modificands. Our main conclusions were: first, that tPPs modify items whose meanings incorporate temporal context variables, and second, that tPPs can apply at either of two levels—before or after determination. We presented a unified account of sentence meanings and tNP meanings in order to allow these two forms of modification, and we showed how correct quantifier scoping results automatically for sentences with multiple tPPs or with tPPs embedded in the complements of other tPPs. We argued that other semantic theories cannot deal systematically with the range of phenomena we considered.

Much work, as ever, remains. In the drive for systematicity, we have paid little attention to the idiosyncrasies of the various English temporal prepositions. We have ignored the vital topics of tense and aspect, as well as the predicative use of temporal prepositions and their role as verb complements. We have disregarded temporal anaphora and indexicality. We have not investigated how our account of temporal prepositions meshes with existing work on non-temporal prepositions, and we have not pursued the inviting generalizations of our motivating observations to non-temporal domains. But despite these unanswered questions, we have nevertheless achieved a considerable degree of systematicity and coverage in our chosen domain. At the very least, the success of our account makes this remaining work worth undertaking.

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