Derivation of temporal preposition meanings in LFG's glue-language approach

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Abstract

This paper investigates the deductive derivation of the semantics of temporal preposition phrases in English in the framework of the glue-language approach as developed for LFG. The meanings of temporal preposition phrases can be given as functions which we call *temporal generalized quantifiers*, as developed in a companion paper using a more traditional syntax-semantics interface. We show that the "glue-language" approach has certain advantage for this task, avoiding some non-standard operations in the λ-calculus used in the alternative, more traditional approach. In particular, we show how to derive scope ambiguities within quantifiers in the modified phrase and quantifier in the modifying phrase, not previously considered in the literature. We propose some modifications to the glue-language approach needed to facilitate the required derivations
Keywords: temporal prepositions, LFG, semantics, linear logic.

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1 Introduction

Most research to date on the formal semantics of temporal expressions in natural languages has focussed on tense and aspect. References are too numerous to list here; see a [8] for a recent survey. Very little research has been devoted to *temporal prepositions* (*TP*s) and *temporal prepositional phrases* (*TPP*s). In a companion paper [7], we develop a rather general formal semantics for the meanings of TPs and TPPs, and show how they temporally modify nouns and VPs by introducing a novel concept of *Temporal Generalized Quantifiers* (TGQs), a natural extension of the classical generalized quantifiers [1]. In doing so, we had to introduce some complicated operations in the λ-calculus, due to the restriction on the order of accessibility to variables imposed by β-reductions (this is explained at the end of section 3.1).

In this paper, we obtain a simpler general and formal analysis of the semantics of TPs and TPPs by using logical deduction of meanings, which allows random access to variables, a property not sufficiently stressed as advantageous in previous uses of this methodology. A deductive approach towards the syntax-semantics interface has recently been developed within the *LFG* [6] framework, using the "resource sensitive" *linear logic (LL)* [5]. The most elaborate treatment within this framework is presented in [4], and we follow closely their approach (and notation). We should note that we are very weakly committed (if at all) to the "resource sensitivity" of LL. Rather, we are more attracted by the general application of logic ("glue language" in the nomenclature of [4]) to deriving the meanings of sentences; the only use of the "resource sensitivity" we make here is the ability to derive "temporary meanings", to be replaced by the "ultimate meaning" as the derivation proceeds. We deviate from [4] in attributing meaning-assembly axioms to minimal f-structures, and not to lexical elements (only).

We first summarize the data we intend to cover. First, we show how to derive the meaning of temporal quantification within TPPs expressed as TGQs. A typical example of the sentences we consider is

(1) Mary kissed John during every meeting.

We take a TPP to include, as components, a preposition (during in (1)) and a *quantified temporal noun-phrase (TNP)* (every meeting in (1)), where the TNP is not in a verb-argument position. However, our account also covers TPPs in which either the preposition or the noun-phrase determiner are not syntactically realized. For example, (2) lacks an overt temporal preposition (as it were: a missing on), whereas (3) lacks an overt quantificational determiner (as it were: a missing the).

(2) Mary kissed John every Friday.

(3) Mary kissed John on Friday.

These syntactically unrealized lexical elements are one source of non-lexical meaning-assembly axioms. A particularly elegant treatment is provided for cascaded TPP modification, as in the sentences below

(4) Mary kissed John during the meeting.

(5) Mary kissed John during the meeting one day.

(6) Mary kissed John during the meeting one day in January.

We also consider more complicated cases of TPPs, where the complement of temporal preposition is a whole sentence like

(7) Bill was envious whenever Mary kissed John.

We cover also cases of scope ambiguity between a quantifier within a TPP and one within a verb-argument position, as in (8)

(8) Mary interviewed every student on a Monday.

This sentence admits of three readings: (i) that there was a certain Monday on which Mary interviewed every one of the students, (ii) that there was a Monday on which Mary collectively interviewed every one of the students, and (iii) that, for every student, there was a Monday on which Mary interviewed him (or her), where the Monday may depend on the student. In [7] we also cover temporal noun modification by TPPs, as in

(9) Mary danced until 2am on Saturday.

Here, on Saturday temporally modifies 2am to create a TPP that modifies the matrix VP. Certain structural ambiguities of TPP attachment arise, and are handled by the proposed semantics. We do not present these derivations here, as they do not illustrate any further advantages of using the glue-language approach beyond the illustration by the derivations presented in this paper.

As it turns out, in order to accommodate temporal modification by TPPs, it is necessary to prepare the ground by changing the (traditional) semantics of simple sentences and their components, to have extra temporal arguments and "hidden" quantifiers over them. Thus, a simple sentence such as

(10) Mary kissed John

expresses a proposition that we want to view as a predicate over time-intervals, within which a kissing event (with the appropriate participants) occurred. Achieving this change requires a respective change in the meanings of nouns, verbs, and the phrases they head. In addition, a (non-temporally-modified) sentence with a quantified verb-argument such as

(11) Mary interviewed every student

displays an ambiguity that manifests itself only in the context of temporal interpretation, generated by a "hidden" scope ambiguity. The one, more prominent, reading is that, several interviewing events (one event per each student) took place, each event with its own, possibly different, occurrence time (depending on the student). Another, less salient, reading is of a "cumulative event" of interviewing of all the students at the same occurrence time. The need of this second reading[1] comes from sentences like

(12) The department chairman was astonished when Mary interviewed every student.

Note that the ambiguity of (11) cannot be explained solely in terms of contribution by lexical elements in the sentence itself. The meaning-assembly axiom for the quantifier causing this ambiguity is another example of a non-lexically-contributed axiom.

A driving idea behind the semantics (as developed in [7]) is that a sentence like (10) can have three different functions in the context of temporal modification: (i) The sentence can have a "stand-alone" meaning, reporting the occurrence of the appropriate kissing event during an appropriate time-interval. (ii) The sentence can be temporally modified by means of a TPP as in (1), where the TPP modification causes the pre-modified sentence Mary kissed John to become the scope of the quantifier every in the TPP. (iii) The sentence can itself serve as a complement of a TPP which modifies some other sentence, as in (7). We refer to these meanings as the stand-alone meaning, pre-modified meaning and modifying meaning, respectively. Providing for all these possibilities explains certain complications in the meanings assigned to temporal nouns and verbs, which are not apparent in the stand-alone reading of sentences.

2 Preliminaries

Our basic framework is that of *LFG* [6] (reprinted in [3]). Syntax has two levels of representation: (i) a *c-structure*, which provides a traditional phrase-structure specification using context-free rules, and (ii) an *f-structure*, which provides a description of the *functional* roles (such as subject, object, etc., taken as primitive notions[2]) by means of *feature-structures* constructed by applying *unification* according to *functional schemata* adjoined to the CF-rules. As we are not dealing here with any syntactic issues, we suppress the c-structure rules and the f-structure-generating schemata. Our point of departure is always an appropriate f-structure, assumed to have been generated by the syntactic analysis. Only the f-structure interfaces to the semantics, via a *projection* mapping σ from f-structures to *semantic structures*, themselves also being feature structures. Semantic structures in turn are assigned formulae in some *meaning language* (having a formal, usually model-theoretic, semantics).

We express meanings in a variant of Montague's *Intensional Logic (IL)* (actually, in the extensional

[1]The availability of this reading depends on the lexical selection of the verb. Some verbs, like see or interview, allow for the collective reading of a multitude of events happening at the same subinterval of the toi. Other verbs, such as kiss or hit seem to block this secondary reading. We do not elaborate on this issue here.

[2]In contrast to configurational definitions of functional elements in other linguistic theories.

fragment of IL, since we do not consider intensional phenomena in this paper). We identify verbs and nouns with IL predicate symbols[3]. The modification of IL we need is the introduction of a new basic type **i**, of temporal intervals. The interpretation of this type in models is *fixed*, expressing the temporal ontology assumed here, namely, intervals of the real line. We use I, J to range over temporal intervals. One could do without this type-extension by regarding temporal intervals as ordinary entities of type **e**. However, in that case, one would need to resort to selectional restrictions in order to explain why (1) is a good sentence, while the similarly typed (13) is unacceptable.

(13) (*) Mary kissed John during every book.

We find the presentation by means of the extra type **i** much clearer and use it in the sequel.

The additional type **i** interacts also with other types in accordance with our intended interpretation of temporal expressions. Thus, propositions are viewed as depending on temporal intervals, and are assigned the type **(i,t)**, instead of their more usual type **t**. In general, propositions (and their components) are evaluated with regard to a *time of interest* (*toi*), the determination of which is discourse-driven. The temporal-interval argument of a proposition originates in the lexical meanings of verbs, and is modified and restricted by constructs like tense, aspect, temporal adverbs and TPPs. We concentrate here on TPPs. Other indexical modifications, e.g., by means of locative PPs, can be similarly handled.

The basic relationship between an f-structure f and a meaning $\mathcal{M}$ (the latter being an IL expression) is represented as an atomic statement of the derivation logic (LL in our case), having the form $f_\sigma \rightsquigarrow_\tau \mathcal{M}$, where f_σ is the semantic projection of f and τ is the type of $\mathcal{M}$ (in IL). We use here the fragment of LL used in [4], in which '$\otimes$' denotes linear conjunction, and '$\multimap$' linear implication. The deduction-rules of LL are used to derive composed meanings from their components. We use the phrase "combining formulae" (of LL) to mean instantiating universal variables via a given substitution, and applying the "linear" modus-ponens rule. All derivations are derivations from assumptions. We refer to such assumptions as *meaning-assembly axioms*. In [4], the meaning-assembly axioms are associated with the lexical entries of the words in the interpreted sentence. As mentioned above, we depart here from [4] in that we associate meaning-assembly axioms with *minimal* f-(sub)structures, and not with words. This provides the possibility, of which we make heavy use, to have meaning-assembly axioms contributed by (minimal) f-(sub)structures that are not μ-related[4] to any node in the c-structure. This move does not affect anything done in [4], but is essential in our context. It has also the methodical advantage that once an f-structure has been constructed, the c-structure and the source sentence can be "forgotten" as far as semantic interpretation is concerned. All meaning-assembly axioms are *instantiated* for the f-structure at hand, and do not refer to LFG's meta-variables. Whenever an f-structure that induces a meaning-assembly axiom does correspond to a lexical entry, we shall continue to refer to that axiom as lexical, to align our presentation with [4]. An alternative possibility, which seems less attractive, would be to associate meaning-assembly axioms with empty categories (which in our case would need to violate the principle of lexical expression of [2]). The use of LL ensures that only derivations that use all assumptions are admissible. The reader is referred to [4] for a discussion of the significance and effect of linearity ("resource sensitivity") of the glue-language logic for this kind of syntax-semantics interface.

3 Non-temporally-modified sentences

We start by deriving meanings of non-temporally-modified sentences (i.e., sentences with no TPPs), to which temporal modification is added subsequently. The derivation is similar to the corresponding derivation in [4], but with the following two main differences: (i) the appropriate revisions of the meaning-assembly axioms related to nouns and verbs, due to their extra temporal arguments (the result of changing the type of prepositions to **(i,t)**), and (ii) the use of non-lexical meaning-assembly axioms. This revision

[3]Sometimes there is a distinction in the literature between, say, the verb kiss and its IL correlate, denoted KISS'. We ignore this distinction here, and use KISS also as an IL relational constant, but in a different font.

[4]Recall that the mapping μ from c-structures to f-structures need not be onto.

is both in the form of the projected semantic structures and the form of the meaning-assembly axioms.

3.1 Quantifier-free sentences

We first exemplify the derivation of meanings of simple sentences on (10) (repeated here as (14))
(14) Mary kissed John.
The meaning representation we intend to derive is:

$$\forall I_{\mathbf{i}}\,(\,(f_\sigma\ \mathrm{TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}} \multimap df_\sigma \rightsquigarrow_{\mathbf{t}} \exists J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J_{\mathbf{i}})]\,)\,.$$

Recall that (14) has three roles (namely, stand-alone, pre-modified and modifying), and we have to cope with all three of them. We start here with the derivation of the stand-alone meaning of (14). However, in order to understand the structure of the f-structure of (14) as shown in Figure 1, we have first to consider briefly its use as a complement of a temporal preposition, as in (7); this issue is elaborated upon in a later section. So, let us ignore for a while the full f-structure *df*, and concentrate first on the f-structure f, which in a way is the "real" f-structure for (14). We assume that f contains the usual 'PRED' feature for the main verb and the usual features for subcategorized complements 'SUBJ', 'OBJ'. In addition, the f-structure f contains a 'SPEC' grammatical function (GF), which does not μ-correspond to any syntactically-realized material in the sentence and its c-structure. This GF is responsible for triggering a non-lexical meaning-assembly axiom (17) (presented below), associated with a "hidden" quantifier (over a temporal variable) in the meaning of (14). This quantifier is responsible for the ambiguity of (11), and we refer to it as the *determination quantifier.* The actual choice of the determination quantifier depends on the temporal preposition which the sentence complements (in a TPP). For stand-alone meanings, this quantifier is always chosen as the existential quantifier **a**. The determination axiom is used in *every* derivation of sentence meaning. Finally, to cope with potential temporal modification, an f-structure of a sentence always has a grammatical function (GF) 'MODS', a set-valued feature, containing the substructures for the TPPs. In the case of (14), which is not temporally modified, this set is empty. We ignore the 'TENSE' GF throughout this paper.

Now, let us explain the nesting of f within *df*. In any use of (14) as a complement within a TPP, the f-structure f of (14) will always be embedded within another f-structure, projecting a scope for the determination quantifier in the meaning of (14). The meaning of (14) itself serves as the restriction of this quantifier, while the sentence in which (14) is embedded (e.g., Bill was envious in (7)) provides the scope of this quantifier. Thus, for the stand-alone meaning of (14), f must also be nested within an f-structure, say *df*, which also is not μ-related to any node in the c-structure of (14). However, in its stand-alone role, (14 does not have a real scope for the determination quantifier. Therefore, *df* has a feature 'DSCOPE', which provides a vacuous "dummy scope" for the determination quantifier by contributing another non-lexical meaning-assembly axiom (15) (presented below), that uses this dummy scope to obtain the final stand-alone sentence meaning. We refer to axiom (15) as the *finalization axiom.* The f-structure *df* also contains a feature 'EMB', representing the grammatical function of the vacuously embedded sentence.

The semantic structure projected from f contains the three features 'EVAR', 'TOI' and 'PRESTR'. 'EVAR' and 'TOI' represent the temporal arguments of the event reported by (14), and 'PRESTR' represents the restriction of the determination quantifier. We thus obtain the relationship shown in Figure 1. The semantic structures df_σ, g_σ and h_σ have no internal structure, and serve only as "placeholders" in LL formulae such as $g_\sigma \rightsquigarrow ...$, and are suppressed from the figure.

Below, we summarize all the axioms that take part in the derivation of the meaning of (14). For *df* we have the meaning-assembly[5] axiom (15), due to the feature 'DSCOPE' (which has as value a minimal f-structure). As explained above, it finalizes the derivation to obtain a stand-alone meaning.
(15) $\forall I_{\mathbf{i}}((df\ \mathrm{EMB})_\sigma \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}}) \multimap df_\sigma \rightsquigarrow_{(\mathbf{i},\mathbf{t})} \lambda I_{\mathbf{i}}[\textsc{true}]$.

[5] In this subsection, we write explicitly the type of each IL variable, and type '$\rightsquigarrow$' according to the type of its LL-target.

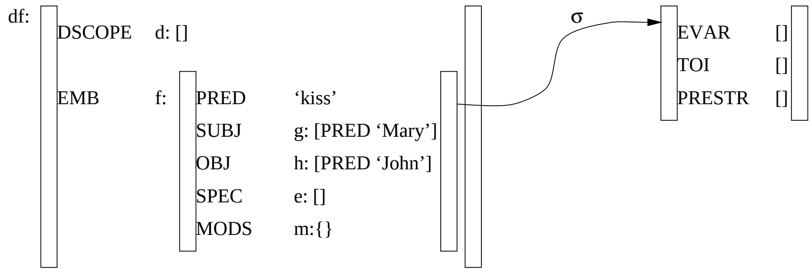

Figure 1: The f-structure and f_σ-structure for Mary kissed John

For f, we have the following axioms. Axiom (16) corresponds roughly to the lexical semantic contribution of kiss in [4]. The reader is referred to [4] for the rationale behind the original axiom, in which the verb has no temporal arguments.

(16) $\forall X_{\mathbf{e}}\forall Y_{\mathbf{e}}\forall J_{\mathbf{i}}\forall I_{\mathbf{i}}(\ ((f_\sigma \text{ EVAR}) \rightsquigarrow_{\mathbf{i}} J_{\mathbf{i}} \otimes (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}} \otimes g_\sigma \rightsquigarrow_{\mathbf{e}} X_{\mathbf{e}} \otimes h_\sigma \rightsquigarrow_{\mathbf{e}} Y_{\mathbf{e}})$
$\multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow_{\mathbf{t}} (J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(X_{\mathbf{e}}, Y_{\mathbf{e}})(J_{\mathbf{i}}))\ )$.

This axiom expresses the following informal paraphrase of the verb[6] meaning. Given values X, Y for the subject and object, given a value I for the toi, and given an occurence time J, the sentence (viewed as a restriction of the determination quantifier) means that an appropriate kissing event takes place at the occurrence time, itself being a subinterval of the toi, Other transitive verbs have similar contributions.

The determination axiom (17) is due to the presence of 'SPEC' in f (with a minimal f-structure as value). For deriving a stand-alone meaning of (14), the axiom has **a** as the determination quantifier.

(17) $\forall R\forall H\forall S\,(\forall J_{\mathbf{i}}\ (f_\sigma \text{ EVAR}) \rightsquigarrow_{\mathbf{i}} J_{\mathbf{i}} \multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow_{\mathbf{t}} R(J_{\mathbf{i}}))$
$\otimes \forall I'_{\mathbf{i}}(f_\sigma \rightsquigarrow_{\mathbf{i}} I'_{\mathbf{i}} \multimap H \rightsquigarrow_{\mathbf{t}} S(I'_{\mathbf{i}}))$
$\multimap H \rightsquigarrow_{\mathbf{t}} \mathbf{a}(R, S)\ )$.

For the substructures g and h, we have the axioms (18) and (19), respectively. These axioms correspond to the lexical axioms for Mary and John, respectively, in [4].

(18) $g_\sigma \rightsquigarrow_{\mathbf{e}} \textsc{mary}$.

(19) $h_\sigma \rightsquigarrow_{\mathbf{e}} \textsc{john}$.

We now present the meaning derivation itself. Combining (16) with the axioms (18) and (19) via the substitution $[X_e \mapsto \textsc{mary}, Y_e \mapsto \textsc{john}]$, we get the core-meaning

(20) $\forall I_{\mathbf{i}}\forall J_{\mathbf{i}}(\ (f_\sigma \text{ EVAR}) \rightsquigarrow_{\mathbf{i}} J_{\mathbf{i}} \otimes (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}}$
$\multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow_{\mathbf{t}} (J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J_{\mathbf{i}}))\ )$.

Combining (20) with the determination axiom (17) via the substitution

$$[\ R \mapsto \lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J_{\mathbf{i}})]\ ]$$

yields

(21) $\forall H\forall S\forall I_{\mathbf{i}}(\ (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}}$
$\otimes \forall I'_{\mathbf{i}}(f_\sigma \rightsquigarrow_{\mathbf{i}} I'_{\mathbf{i}} \multimap H \rightsquigarrow_{\mathbf{t}} S(I'_{\mathbf{i}}))$
$\multimap\ H \rightsquigarrow_{\mathbf{t}} \mathbf{a}(\lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J_{\mathbf{i}})], S)\ )$.

Finally, combining (21) with (15) via the substitution $[\ [S \mapsto \lambda I[\textsc{true}], H \mapsto df_\sigma\ ]$, we get

(22) $\forall I_{\mathbf{i}}(\ (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}} \multimap\ df_\sigma \rightsquigarrow_{\mathbf{t}} \mathbf{a}(\lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J_{\mathbf{i}})], \lambda x[\textsc{true}])\ )$,

which can be further simplified to

(23) $\forall I_{\mathbf{i}}\ (\ (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}} \multimap df_\sigma \rightsquigarrow_{\mathbf{t}} \exists J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J_{\mathbf{i}})]\ )$.

Thus, the final stand-alone meaning of (14) can be paraphrased as follows. Given an evaluation time I, there exists an occurrence time J, which is a subinterval of I, over which Mary kissed John. LL formulae like (21) represent TGQs, expressions of the form $\lambda P_{(\mathbf{i},\mathbf{t})}\lambda I_{\mathbf{i}}[\phi(P, I)]$.

[6]We concentrate in this paper on one aspectual class of verbs, namely event-reporting ones. A semantics for for TPP temporal modification of sentences headed by stative verbs can be found in [7].

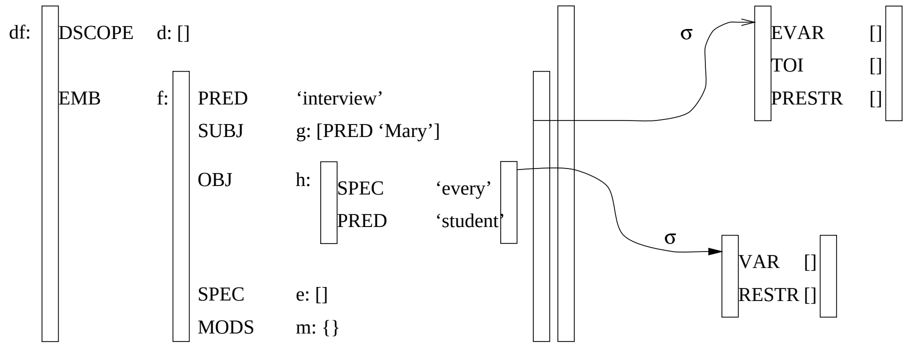

Figure 2: The f-structure and f_σ-structure for Mary interviewed every student

We would like to draw attention to a feature of the "glue-language" approach, seen in the above derivation, but not noted previously (or at least not suffiently stressed) as an advantage compared to more conventional syntax-semantics interfaces. Consider again the axiom (16), contributed by a transitive verb (kiss in this case). The antecedent of the linear implication consists of three linear conjuncts. As linear conjunction is commutative and assoiative, *each* conjunct can be used for linear modus ponens (under the appropriate substitution for the universally quantified variables in that conjunct). No ordering is imposed on access to verb-arguments or indexical arguments. This should be contrasted with a direct IL representation of the meaning of kiss as a λ-expression. Some particular order has to be imposed on the arguments. The order used in [7] is $\lambda y \lambda J \lambda x \lambda I[\text{KISS}(x,y)(J) \wedge I \subseteq J]$. This imposes an order of functional application, which occasionally has to be overruled. In [7], special operations were introduced to the λ-calculus to overcome this difficulty. In the glue-language approach, it comes for free (this feature is independent of the particular choice of LL; any other logic that allows decomposing meaning representations and accessing their components would do).

3.2 Quantified subcategorized arguments

Next, we extend the derivation to temporally unmodified sentences in which the verb-arguments may be quantified. We exemplify the approach by deriving the two meanings of

(24) Mary interviewed every student.

Note again that there is no way to explain the ambiguity of this sentence by alluding only to meaning-assembly contributions of its lexical elements. The f-structure is similar to that in (1), but the value of 'OBJ' is a substructure h containing a 'SPEC' function, with value 'every' for (24), and 'PRED' with value 'student' for (24). The semantic projection h_σ has the two additional features: 'VAR' - for the (implicit) variable ranging over the domain of quantification, and 'RESTR' - for the quantifier-restrictor, determining that domain. The situation is summarized in Figure 2.

For interviewed (similarly to (16) for kissed), we have

(25) $\forall X_{\mathbf{e}} \forall Y_{\mathbf{e}} \forall I_{\mathbf{i}} \forall J_{\mathbf{i}}(\; ((f_\sigma \text{ EVAR}) \rightsquigarrow_{\mathbf{i}} J_{\mathbf{i}} \otimes (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}} \otimes g_\sigma \rightsquigarrow_{\mathbf{e}} X_{\mathbf{e}} \otimes h_\sigma \rightsquigarrow_{\mathbf{e}} Y_{\mathbf{e}})$
$\multimap \; (f_\sigma \text{ PRESTR}) \rightsquigarrow_{\mathbf{t}} (J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(X_{\mathbf{e}}, Y_{\mathbf{e}})(J_{\mathbf{i}})) \;)$.

We adopt from [4] the (instantiated) axioms (26), and (27). The reader is again referred to [4] for the rationale behind (26) and (27).

(26) $\forall R' \forall H' \forall S'(\; \forall Y_{\mathbf{e}}((h_\sigma \text{ VAR}) \rightsquigarrow_{\mathbf{e}} Y_{\mathbf{e}} \; \multimap \; (h_\sigma \text{ RESTR}) \rightsquigarrow_{\mathbf{t}} R'(Y_{\mathbf{e}}))$
$\otimes \forall Y_{\mathbf{e}}(h_\sigma \rightsquigarrow_{\mathbf{e}} Y_{\mathbf{e}} \; \multimap \; H' \rightsquigarrow_{\mathbf{t}} S'(Y_{\mathbf{e}}))$
$\multimap \; H' \rightsquigarrow_{\mathbf{t}} \mathbf{every}(\lambda x[R'(x)], \lambda x[S'(x)]) \;)$.

Note that some bound variables have been renamed by primes, to distinguish them from those in (17).

(27) $\forall Y_{\mathbf{e}}(\; (h_\sigma \text{ VAR}) \rightsquigarrow_{\mathbf{e}} Y_{\mathbf{e}} \; \multimap \; (h_\sigma \text{ RESTR}) \rightsquigarrow_{\mathbf{t}} \text{STUDENT}(Y_{\mathbf{e}}) \;)$.

In addition, we have the non-lexical determination axiom (17), finalization axiom (15), and the lexical axiom (18) for Mary, as before.

The first derivation starts by combining (26) with (27), using the substitution $[R' \mapsto \text{STUDENT}]$, and yielding (28) as the meaning[7] of 'every student':

(28) $\forall H'\forall S'(\forall Y_{\mathbf{e}}(h_\sigma \leadsto_{\mathbf{e}} Y_{\mathbf{e}} \multimap H' \leadsto_{\mathbf{t}} S'(Y_{\mathbf{e}}))$
$\multimap H' \leadsto_{\mathbf{t}} \mathbf{every}(\lambda Y_{\mathbf{e}}[\text{STUDENT}(Y_{\mathbf{e}})], \lambda Y_{\mathbf{e}}[S'(Y_{\mathbf{e}})]))$.

Combining (25) with (18) using the substitution $[X_{\mathbf{e}} \mapsto \text{MARY}]$ yields the meaning (29) for Mary interviewed:

(29) $\forall Y_{\mathbf{e}}\forall I_{\mathbf{i}}\forall J_{\mathbf{i}}(((f_\sigma \text{ EVAR}) \leadsto_{\mathbf{i}} J_{\mathbf{i}} \otimes (f_\sigma \text{ TOI}) \leadsto_{\mathbf{i}} I_{\mathbf{i}} \otimes h_\sigma \leadsto_{\mathbf{e}} Y_{\mathbf{e}})$
$\multimap (f_\sigma \text{ PRESTR}) \leadsto_{\mathbf{t}} (J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y_{\mathbf{e}})(J_{\mathbf{i}}))$).

By combining (29) with (28), using the substitution

$$[H' \mapsto (f_\sigma \text{ PRESTR}), S' \mapsto \lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y_{\mathbf{e}})(J_{\mathbf{i}})]\ ]$$

(representing the low-scope choice for every), we get

(30) $\forall I_{\mathbf{i}}\forall J_{\mathbf{i}}(\ (f_\sigma \text{ EVAR}) \leadsto_{\mathbf{i}} J_{\mathbf{i}} \otimes (f_\sigma \text{ TOI}) \leadsto_{\mathbf{i}} I_{\mathbf{i}}$
$\multimap (f_\sigma \text{ PRESTR}) \leadsto_{\mathbf{t}} \mathbf{every}(\lambda Y^1_{\mathbf{e}}[\text{STUDENT}(Y^1_{\mathbf{e}})],$
$\lambda Y^2_{\mathbf{e}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y^2_{\mathbf{e}})(J_{\mathbf{i}})])$).

We now proceed as in the quantifier-free case. Combining (30) with the determination axiom (17) via the substitution

$$[\ [R \mapsto \lambda J_{\mathbf{i}}[\mathbf{every}(\lambda Y^1_{\mathbf{e}}[\text{STUDENT}(Y^1_{\mathbf{e}})], \lambda Y^2_{\mathbf{e}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y^2_{\mathbf{e}})(J_{\mathbf{i}})])]\ ],$$

we get

(31) $\forall H \forall S \forall I_{\mathbf{i}}(\ (f_\sigma \text{ TOI}) \leadsto_{\mathbf{i}} I_{\mathbf{i}}$
$\otimes \forall I'_{\mathbf{i}}(f_\sigma \leadsto_{\mathbf{i}} I'_{\mathbf{i}} \multimap H \leadsto S(I'_{\mathbf{i}}))$
$\multimap H \leadsto_{\mathbf{t}} \mathbf{a}(\lambda J_{\mathbf{i}}[\mathbf{every}(\lambda Y^1_{\mathbf{e}}[\text{STUDENT}(Y^1_{\mathbf{e}})],$
$\lambda Y^2_{\mathbf{e}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y^2_{\mathbf{e}})(J_{\mathbf{i}})])], S)$).

Finally, (31) is combined with the finalization axiom (15) via the substitution

$$[\ S \mapsto \lambda I[\text{TRUE}], H \mapsto df_\sigma\ ]$$

and simplifying as before, we get the final stand-alone meaning of (24),

(32) $\forall I_{\mathbf{i}}(\ (f_\sigma \text{ TOI}) \leadsto_{\mathbf{i}} I_{\mathbf{i}} \multimap df_\sigma \leadsto_{\mathbf{t}} \exists J_{\mathbf{i}}[\mathbf{every}(\lambda Y^1_{\mathbf{e}}[\text{STUDENT}(Y^1_{\mathbf{e}})],$
$\lambda Y^2_{\mathbf{e}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y^2_{\mathbf{e}})(J_{\mathbf{i}})])]$).

This is the "collective event" (secondary) reading of (24).

To derive the primary reading of (24), we first derive (29) as before. Next, we combine (29) with the determination axiom (17) via the substitution $[R \mapsto \lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y_{\mathbf{e}})(J_{\mathbf{i}})]\ ]$ to get

(33) $\forall H \forall S \forall I_{\mathbf{i}}\,((f_\sigma \text{ TOI}) \leadsto_{\mathbf{i}} I_{\mathbf{i}} \otimes h_\sigma \leadsto_{\mathbf{e}} Y_{\mathbf{e}}$
$\otimes \forall I'_{\mathbf{i}}(f_\sigma \leadsto_{\mathbf{i}} I'_{\mathbf{i}} \multimap H \leadsto S(I'_{\mathbf{i}}))$
$\multimap H \leadsto_{\mathbf{t}} \mathbf{a}(\lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y_{\mathbf{e}})(J_{\mathbf{i}})], S)$).

Next, we derive (28) as before, and combine it with (33) via the substitution

$$[\ H' \mapsto H, S' \mapsto \mathbf{a}(\lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y_{\mathbf{e}})(J_{\mathbf{i}})], S)\ ]$$

(representing a high-scope choice for every). We get

(34) $\forall H \forall S \forall I_{\mathbf{i}}(\ (f_\sigma \text{ TOI}) \leadsto_{\mathbf{i}} I_{\mathbf{i}}$
$\otimes \forall I'_{\mathbf{i}}(f_\sigma \leadsto_{\mathbf{i}} I'_{\mathbf{i}} \multimap H \leadsto_{\mathbf{t}} S(I'_{\mathbf{i}}))$
$\multimap H \leadsto_{\mathbf{t}} \mathbf{every}(\lambda Y^1_{\mathbf{e}}[\text{STUDENT}(Y^1_{\mathbf{e}})],$
$\lambda Y^2_{\mathbf{e}}[\mathbf{a}(\lambda J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y^2_{\mathbf{e}})(J_{\mathbf{i}})], S))$).

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[7] For clarity, we identify the LL-variable quantified over by **every** and the glue-language variable associated with object projection h_σ, and use $Y_{\mathbf{e}}$ for both.

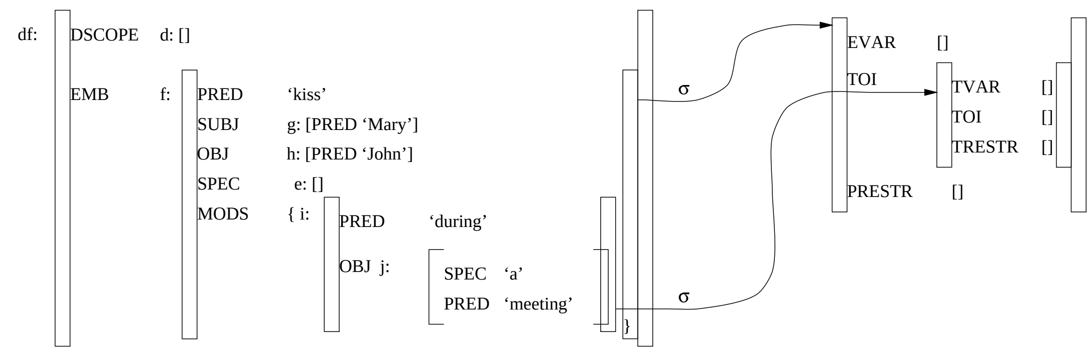

Figure 3: The f-structure and f_σ-structure for Mary kissed John during a meeting

Finally, combining (34) with the finalization meaning-assembly axiom (15) with the same substitution $[S \mapsto \lambda I[\text{TRUE}], H \mapsto df_\sigma]$, and simplifying, we get as the second stand-alone reading of (24)

(35) $\forall I_{\mathbf{i}}(\ (f_\sigma \text{ TOI}) \rightsquigarrow_{\mathbf{i}} I_{\mathbf{i}}$
$\quad\multimap\ df_\sigma \rightsquigarrow_{\mathbf{t}} \mathbf{every}(\lambda Y^1_{\mathbf{e}}[\text{STUDENT}(Y^1_{\mathbf{e}})],$
$\qquad\qquad \lambda Y^2_{\mathbf{e}}[\exists J_{\mathbf{i}}[J_{\mathbf{i}} \subseteq I_{\mathbf{i}} \wedge \text{INTERVIEW}(\text{MARY}, Y^2_{\mathbf{e}})(J_{\mathbf{i}})]])\ ).$

4 Temporally modified sentences

4.1 Derivations with TPPs and quantifier-free verb-arguments

We now proceed to derive meanings[8] of temporally modified sentences. We start with sentences without quantifiers in verb-arguments, and with a single TPP with a TNP complement; sentences with TPPs with sentential complement are treated in section 5. As an example, we derive the meaning of (36).

(36) Mary kissed John during a meeting.

The f-structure is as in Figure 1, but with the value of 'MODS' being non-empty. It contains a substructure i, itself containing a substructure j for the TGQ. Note the nesting of j_σ within $(f_\sigma$ TOI), which plays an important role in the derivation. The situation is summarized in Figure 3.

We have the following axioms for this f-structure. We have, as before, the lexical axioms (16) (for kiss), (18) (for Mary), and (19) (for John), as well as the nonlexical axioms (15) and (17). In addition, we have (37) (for a in the TPP, viewed as a TGQ).

(37) $\forall R''\forall H''\forall S''(\forall J''((j_{2_\sigma} \text{ TVAR}) \rightsquigarrow J'' \multimap (j_{2_\sigma} \text{ TRESTR}) \rightsquigarrow R''(J''))$
$\qquad \otimes \forall I''(j_{2_\sigma} \rightsquigarrow I'' \multimap H'' \rightsquigarrow S''(I''))$
$\qquad \multimap\ H'' \rightsquigarrow \mathbf{a}(\lambda J[R''(J)], \lambda I[S''(I)]))$

The temporal noun meeting lexically contributes (38),

(38) $\forall I''\forall J''((j_\sigma \text{ TVAR}) \rightsquigarrow J'' \otimes (j_\sigma \text{ TOI}) \rightsquigarrow I'' \multimap (j_\sigma \text{ TRESTR}) \rightsquigarrow J'' \subseteq I'' \wedge \text{MEETING}(J'')).$

Thus, (38) can be viewed as assigning to meeting the predicates that holds of I and J if J is the occurrence time of a meeting within the time of interest I. Note the similarity between meanings of temporal nouns and verbs, both having the form $\lambda I \lambda J[\phi(I, J)]$. The TP during has a null contribution to the meaning of the TPP, and therefore contributes no axiom. We deal with more contentful temporal prepositions later.

We now proceed with the derivation itself. First, we combine (37) with (38) via the substitution

$$[\ R' \mapsto \lambda J''[J'' \subseteq I'' \wedge \text{MEETING}(J'')]\ ],$$

[8] We henceforth suppress type-indices of variables.

to get (39) as the meaning of a meeting.

(39) $\forall H'\forall S'\forall I''((j_\sigma \text{ TOI}) \rightsquigarrow I''$
$\otimes\forall I'(j_\sigma \rightsquigarrow I' \multimap H' \rightsquigarrow S'(I'))$
$\multimap\ H' \rightsquigarrow \mathbf{a}(\lambda J[J \subseteq I''\wedge\text{MEETING}(J'')], \lambda I[S'(I)])\ )$.

Next, (20) is derived as before. Now, in view of the identification $(f_\sigma \text{ TOI}) \equiv j_\sigma$, we can combine (20) with (39) using substitution

$$[\ S' \mapsto \lambda I[J \subseteq I\wedge\text{KISS}(\text{MARY}, \text{JOHN})(J)], H' \mapsto (f_\sigma \text{ PRESTR})\ ]$$

to obtain

(40) $\forall I''\forall J((j_\sigma \text{ TOI}) \rightsquigarrow I'' \otimes (f_\sigma \text{ EVAR}) \rightsquigarrow J$
$\multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow \mathbf{a}(\lambda J'[J' \subseteq I''\wedge\text{MEETING}(J')],$
$\lambda I[J \subseteq I\wedge\text{KISS}(\text{MARY}, \text{JOHN})(J)]))$.

Note the similarity of the LL expression of meanings of temporal nouns to that of verbs. A temporal noun is also viewed as a predicate over two temporal intervals.

From here the derivation proceeds as in the non-modified case. We combine (40) with the determination axiom (17), using substitution

$$[R \mapsto \mathbf{a}(\lambda J'[J' \subseteq I''\wedge\text{MEETING}(J')], \lambda I[J \subseteq I\wedge\text{KISS}(\text{MARY}, \text{JOHN})(J)]),\ I \mapsto I'']$$

yielding

(41) $\forall H\forall S\forall I''((f_\sigma \text{ TOI}) \rightsquigarrow I''$
$\otimes\forall x(f_\sigma \rightsquigarrow x \multimap H \rightsquigarrow S(x))$
$\multimap\ H \rightsquigarrow \mathbf{a}(\lambda J[\mathbf{a}(\lambda J'[J' \subseteq I''\wedge\text{MEETING}(J')],$
$\lambda I[J \subseteq I\wedge\text{KISS}(\text{MARY}, \text{JOHN})(J)])], S)\ )$.

Finally, combining (41) with the finalization axiom (15), using the substitution $[R \mapsto \lambda x[\text{TRUE}], H \mapsto df_\sigma]$, the final meaning obtained for (36) is

(42) $\forall I''((f_\sigma \text{ TOI}) \rightsquigarrow I'' \multimap df_\sigma \rightsquigarrow \exists J[\mathbf{a}(\lambda J'[J' \subseteq I''\wedge\text{MEETING}(J')],$
$\lambda I[J \subseteq I\wedge\text{KISS}(\text{MARY}, \text{JOHN})(J)])]\ )$.

Note that for the sentence

(43) Mary kissed John on Saturday

a similar derivation is obtained. The f-structure also contains a 'SPEC' GF within j, with value 'the', in spite of the non lexical realization of an overt determiner 'the' within the TPP. This substructure contributes the the-analogon of the a axiom in the previous derivation. The final meaning derived for (43) is (44).

(44) $\forall I''((f_\sigma \text{ TOI}) \rightsquigarrow I'' \multimap df_\sigma \rightsquigarrow \exists J[\mathbf{the}(\lambda J'[J' \subseteq I''\wedge\text{STURDAY}(J')],$
$\lambda I[J \subseteq I\wedge\text{KISS}(\text{MARY}, \text{JOHN})(J)])]\ )$.

Next, we turn to cascaded TPP-modification. Consider the sentence

(45) Mary kissed John during a meeting one day

The f-structure and its projection are shown in Figure 4; it contains a 'MODS'-value which is a two-elements set, one element for each TPP. Note that $(f_\sigma \text{ TOI}) \equiv j_{1_\sigma} \equiv j_{2_\sigma}$. The axioms for this f-structure are all the axioms present in the previous derivation (with j_1 replacing j everywhere), as well as the additional lexical axiom (46), corresponding to the TN day.

(46) $\forall I'''\forall J'''((j_{2_\sigma} \text{ TVAR}) \rightsquigarrow J''' \otimes (j_{2_\sigma} \text{ TOI}) \rightsquigarrow I'''$
$\multimap (j_{2_\sigma} \text{ TRESTR}) \rightsquigarrow J''' \subseteq I'''\wedge\text{DAY}(J'''))$.

Note that 'on' is also a vacuous temporal preposition and contributes no axiom.

The derivation starts with the combination of (37) and (46) using substitution

$$[\ R''' \mapsto \lambda J'''[J''' \subseteq I'''\wedge\text{DAY}(J''')]\ ]$$

to get the meaning (47) for one day.

(47) $\forall H'''\forall S'''(\forall I'''(j_{2_\sigma} \text{ TOI}) \rightsquigarrow I'''$
$\otimes\forall I'(j_{2_\sigma} \rightsquigarrow I' \multimap H''' \rightsquigarrow S'''(I'))$
$\multimap\ H''' \rightsquigarrow \mathbf{a}(\lambda J[J \subseteq I'''\wedge\text{DAY}(J''')], \lambda I[S'''(I)]))$.

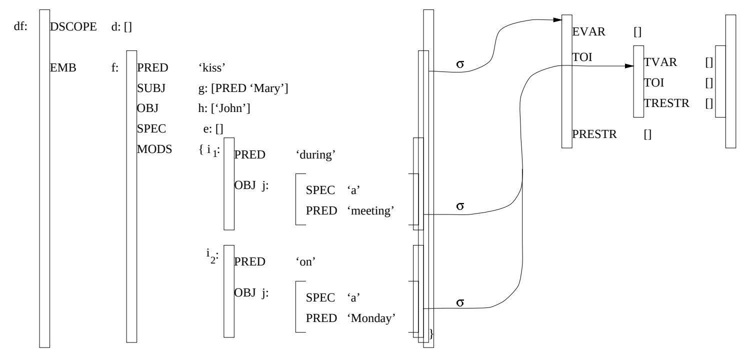

Figure 4: The f-structure and f_σ-structure for Mary kissed John during a meeting one day

Next, (48) is derived similarly to (40) before, with j_1 instead of j.

(48) $\forall I'''\forall J((j_{1_\sigma}\ \text{TOI}) \rightsquigarrow I''' \otimes (f_\sigma\ \text{EVAR}) \rightsquigarrow J$
$\quad\multimap (f_\sigma\ \text{PRESTR}) \rightsquigarrow \mathbf{a}(\lambda J'[J' \subseteq I''' \wedge \text{MEETING}(J')],$
$\quad\quad \lambda I[J \subseteq I \wedge \text{KISS}(\text{MARY}, \text{JOHN})(J)]))$.

Next, (48) is combined with (47) using substitution

$$[S''' \mapsto \mathbf{a}(\lambda J'[J' \subseteq I''' \wedge \text{MEETING}(J')], \lambda I[J \subseteq I \wedge \text{KISS}(\text{MARY}, \text{JOHN})(J)]),\ H''' \mapsto (f_\sigma\ \text{PRESTR})]$$

yielding (49).

(49) $\forall I'''\forall J((j_{2_\sigma}\ \text{TOI}) \rightsquigarrow I''' \otimes (f_\sigma\ \text{EVAR}) \rightsquigarrow J$
$\quad\multimap (f_\sigma\ \text{PRESTR}) \rightsquigarrow \mathbf{a}(\lambda J''[J'' \subseteq I'' \wedge \text{DAY}(J'')],$
$\quad\quad \lambda I'[\mathbf{a}(\lambda J'[J' \subseteq I' \wedge \text{MEETING}(J')],$
$\quad\quad\quad \lambda I[J \subseteq I \wedge \text{KISS}(\text{MARY}, \text{JOHN})(J)])]))$.

Now the usual continuation follows. After combining (49) with the determination and finalization axioms, and after the quantifier simplification, we get (50) as the final meaning.

(50) $\forall I'''(\ (f_\sigma\ \text{TOI}) \rightsquigarrow I'''$
$\quad\multimap df_\sigma \rightsquigarrow \exists J[\mathbf{a}(\lambda J''[J'' \subseteq I''' \wedge \text{DAY}(J'')],$
$\quad\quad \lambda I'[\mathbf{a}(\lambda J'[J' \subseteq I' \wedge \text{MEETING}(J')],$
$\quad\quad\quad \lambda I[J \subseteq I \wedge \text{KISS}(\text{MARY}, \text{JOHN})(J)])])]\ )$

By parity of treatment, suppressing the details of the derivation, we get for (6), repeated as (51),

(51) Mary kissed John during the meeting one day in January,

the final meaning (52) (where temporal variables were indexed for clarity)

(52) $\forall I_3(\ (f_\sigma\ \text{TOI}) \rightsquigarrow I_3$
$\quad\multimap df_\sigma \rightsquigarrow \exists J_0[\mathbf{the}(\lambda J_3[\text{JANUARY}(J_3) \wedge J_3 \subseteq I_3],$
$\quad\quad \lambda I_2[\mathbf{a}(\lambda J_2[J_2 \subseteq I_2 \wedge \text{DAY}(J_2)],$
$\quad\quad\quad \lambda I_1[\mathbf{a}(\lambda J_1[J_1 \subseteq I_1 \wedge \text{MEETING}(J_1)],$
$\quad\quad\quad\quad \lambda I_0[J_0 \subseteq I_0 \wedge \text{KISS}(\text{MARY}, \text{JOHN})(J_0)])])]\ )$.

A note of caution regarding universal quantification such as (1), repeated here as (53):

(53) Mary kissed John during every meeting

By a derivation like that for (36) (with the obvious change in the (MODS PRED) to 'every'), using the axiom (54) below for **every**) and combining with the determination axiom *after* the combination with (54), a degenerate meaning (55) is obtained.

(54) $\forall R'\forall H'\forall S'(\ \forall J'((j_\sigma\ \text{TVAR}) \rightsquigarrow J' \multimap\ (j_\sigma\ \text{TRESTR}) \rightsquigarrow R'(J'))$
$\quad \otimes\forall I'(j_\sigma \rightsquigarrow I' \multimap H' \rightsquigarrow S'(I'))$
$\quad \multimap\ H' \rightsquigarrow \mathbf{every}(\lambda J[R'(J)], \lambda I[S'(I)])\ )$.

(55) $\forall I''(\ (f_\sigma\ \text{TOI}) \rightsquigarrow I'' \multimap df_\sigma \rightsquigarrow \exists J[\mathbf{every}(\lambda J'[J' \subseteq I'' \wedge \text{MEETING}(J')],$
$\quad \lambda I[J \subseteq I \wedge \text{KISS}(\text{MARY}, \text{JOHN})(J)])]\ )$.

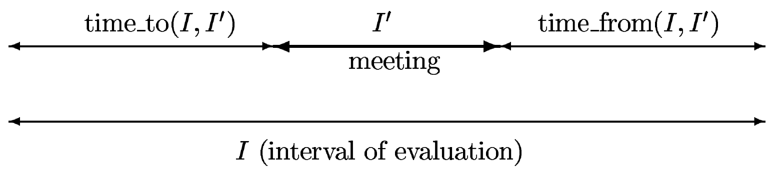

Figure 5: Simple representation of before, during and after.

If meetings are disjoint, this meaning is identically false. To obtain the right meaning, another order of combination is used. The combination with the determination axiom is done *before* combination with the wider scoping axiom for **every**. We do not repeat the details. The final result is

(56) $\forall I''(\ (f_\sigma\ \mathrm{TOI}) \leadsto I'' \multimap df_\sigma \leadsto [\mathbf{every}(\lambda J'[J' \subseteq I'' \land \textsc{meeting}(J')],$
$\lambda I[\exists J[J \subseteq I \land \textsc{kiss}(\textsc{mary}, \textsc{john})(J)]])]\ ).$

Using this order of combination with the axioms of the previous examples yields equivalent meanings.

Thus, we see that cascaded TPP-modification is treated smoothly, where "old" meanings are consumed, and their temporally modified counterpart replaces them for further combination with other axioms. Clearly, this process may continue for any number of TPPs. Their order of removal from the set is controled by additional calendrical knowledge.

4.1.1 More on temporal prepositions

We present another example of a derivation, this time with a temporal preposition that does contribute an axiom. A more extensive discussion of the contribution of various temporal prepositions can be found in [7]. As a typical example, we derive the meaning of (57).

(57) Mary kissed John before the meeting

The f-structure for (57) is similar to that of Figure 3, with the obvious changes (i PRED) = 'before′ and (j SPEC) = 'the′. The semantic projection is identical to that of Figure 3. We note here that the intended informal meaning of before is 'some time before'. There is another meaning, namely, 'just before', needed for sentences like

(58) Mary kissed John before every meeting.

which we do not deal with in this paper.

To formalize the meaning of before we introduce a function time_to(I, I'), of type $(\mathbf{i} \otimes \mathbf{i}, \mathbf{i})$, defined for $I = [a, b]$, $I' = [c, d]$, such that $a \leq c$ and $b \geq d$, by: time_to$([a, b], [c, d]) =_{\mathrm{Def}} [a, c]$. For the meaning of after, a similar function time_from is defined by time_from$([a, b], [c, d]) =_{\mathrm{Def}} [d, b]$. The relationship among the intervals (for I' the unique meeting-interval in I) is shown in Figure 5. These functions are also used in formalizing the meanings of temporal prepositions such as until, since, by etc., not further persued in this paper. The axiom contributed by before is (59). We refer the reader to [7] for the rationale behind it.

(59) $\forall \mathbf{Q} \forall T \forall H \forall S \forall I^*(\ ((j_\sigma\ \mathrm{TOI}) \leadsto I^* \otimes \forall I'(j_\sigma \leadsto I' \multimap H \leadsto S(I'))$
$\multimap H \leadsto \mathbf{Q}(\lambda J[T(J) \land J \subseteq I^*], \lambda I[S(I)]))$
$\multimap$
$((j_\sigma\ \mathrm{TOI}) \leadsto I^* \otimes \forall I'(j_\sigma \leadsto I' \multimap H \leadsto S(I'))$
$\multimap H \leadsto \mathbf{Q}(\lambda J[T(J) \land J \subseteq I^*], \lambda I[S(\mathrm{time\_to}(I^*, I))])\ ).$

By this axiom, the effect of before is to consume a TNP-meaning and produce another meaning of the same form, where a *time warp* of the temporal argument takes place, via the function time_to, an application of which is spliced in the appropriate place in the LL-formula. Here we can see once more the advantage of using the glue-language approach, that allows a direct modification of I to time_to(I^*, I) within a sub-formula.

The definite article the contributes (in analogy to (54)) the axiom (60).

(60) $\forall R'\forall H'\forall S'(\ \forall J'((j_\sigma\ \mathrm{TVAR}) \rightsquigarrow J' \multimap\ (j_\sigma\ \mathrm{TRESTR}) \rightsquigarrow R'(J'))$
$\otimes\forall I'(j_\sigma \rightsquigarrow I' \multimap H' \rightsquigarrow S'(I'))$
$\multimap\ H' \rightsquigarrow \mathbf{the}(\lambda J[R'(J)], \lambda I[S'(I)])\ ).$

Note that we keep here the Russelian explication of the definite the for uniformity only. It can be easily interpreted in one of the more recent approaches based on familiarity.

We now describe the derivation itself. First, similarly as before, the meaning of the TNP the meeting is derived by combining (38) with (60) with the obvious substitution, yielding (61).

(61) $\forall H'\forall S'\forall I''(\ (j_\sigma\ \mathrm{TOI}) \rightsquigarrow I''$
$\otimes\forall I'(j_\sigma \rightsquigarrow I' \multimap H' \rightsquigarrow S'(I'))$
$\multimap\ H' \rightsquigarrow \mathbf{the}(\lambda J[J \subseteq I'' \wedge \textsc{meeting}(J'')], \lambda I[S'(I)])\ ).$

Next, (61) is combined with the before-axiom (59) using substitution

$$[\ I'' \mapsto I^*,\ \mathbf{Q} \mapsto \mathbf{the},\ T \mapsto \lambda J'[\textsc{meeting}(J')]\ ],$$

yielding (62).

(62) $\forall H\forall S\forall I^*(\ (j_\sigma \mathrm{TOI}) \rightsquigarrow I^*$
$\otimes\forall I'(j_\sigma \rightsquigarrow I' \multimap H \rightsquigarrow S(I'))$
$\multimap H \rightsquigarrow \mathbf{the}(\lambda J'[\textsc{meeting}(J') \wedge J' \subseteq I^*], \lambda I[S(\mathrm{time\_to}(I^*, I))])\ ).$

As (62) has the same form as as (39) above, the derivation proceeds along the same lines. Combining (62) with (20) (the meaning of Mary kissed John), again using an obvious substitution, yields (63).

(63) $\forall I^*\forall J(\ (j_\sigma\ \mathrm{TOI}) \rightsquigarrow I^* \otimes (f_\sigma\ \mathrm{EVAR}) \rightsquigarrow J$
$\multimap (f_\sigma\ \mathrm{PRESTR}) \rightsquigarrow \mathbf{the}(\lambda J'[\textsc{meeting}(J') \wedge J' \subseteq I^*],$
$\lambda I[\textsc{kiss}(\textsc{mary}, \textsc{john})(J) \wedge J \subseteq \mathrm{time\_to}(I^*, I)])\ ).$

Thus, (63) clearly reflects the anchoring of the occurrence-time of the kissing event to some time preceeding the unique meeting-interval within the toi. The rest of the derivation is by now standard. After combining with the determination and finalization axioms (with the appropriate substitutions) and after simplifying, we get as (64) as the final meeting.

(64) $\forall I^*(\ (f_\sigma\ \mathrm{TOI}) \rightsquigarrow I^* \multimap df_\sigma\ \rightsquigarrow \exists J[\mathbf{the}(\lambda J'[\textsc{meeting}(J') \wedge J' \subseteq I^*],$
$\lambda I[\textsc{kiss}(\textsc{mary}, \textsc{john})(J) \wedge J \subseteq \mathrm{time\_to}(I^*, I)])]\ ).$

4.2 Derivations with TPPs and quantified verb-arguments

We now turn to the derivation of meanings of sentences in which both subcategorized verb-arguments and *TPPs* are possibly quantified. These sentences are three-way ambiguous, the ambiguity originating from three possible non-equivalent arrangements of the verb-argument quantifier, the TPP quantifier and the covert determination quantifier. Thus, we have to generate three different derivations from the same assumptions. However, we already know that such derivations reduce to different order of combination of intermediately deduced formulae, which falls out naturally from the glue-language methodology. As a typical example sentence, we reconsider our previous sentence, repeated here as (65):

(65) Mary interviewed every student on a Monday.

The f-strucure of (65) and its σ-projection are shown in Figure 6.

For this f-structure, the following axioms are generated. First, we have the lexical axioms (25) for interviewed, (18) for Mary, (26) for the e-typed every, (27) for student, (37) for i-typed a, and the following axiom (66) for Monday.

(66) $\forall I^*\forall J^*(\ (j_\sigma\ \mathrm{TVAR}) \rightsquigarrow J^* \otimes (j_\sigma\ TOI) \rightsquigarrow I^*$
$\multimap(j_\sigma\ \mathrm{TRESTR}) \rightsquigarrow J^* \subseteq I^* \wedge \textsc{monday}(J^*)\ ).$

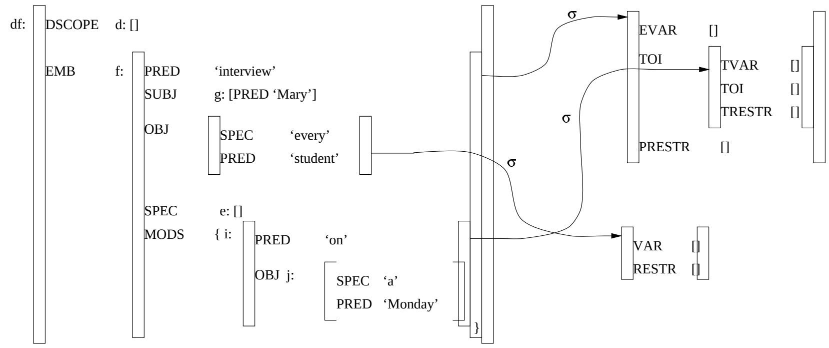

Figure 6: The f-structure and f_σ-structure for Mary interviewed every student on a Monday

In addition, we have the non-lexical axioms for determination (17) and finalization (15). Recall that on makes a null contribution to the meaning-assembly axioms.

The first derivation starts by repeating the steps in the derivation of (30), the meaning of Mary interviewed every student, repeated here as (67).

(67) $\forall I \forall J(\ (f_\sigma \text{ EVAR}) \rightsquigarrow J \otimes (f_\sigma \text{ TOI}) \rightsquigarrow I$
$\multimap\ (f_\sigma \text{ PRESTR}) \rightsquigarrow \textbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)],$
$\lambda Y_2[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y_2)(J)])\ ).$

Note that repeating the derivation in the environment of the current f-structure for (65) is possible because the f-structure for (24) *subsumes* that of (65). Combining (37) with (66) using substitution

$$[R \mapsto \lambda J[J^* \subseteq I^* \wedge \text{MONDAY}(J^*)],\ J'' \mapsto J^*]$$

yields (68) as the meaning of a Monday.

(68) $\forall H'' \forall S'' \forall I^*(\ (j_\sigma \text{ TOI}) \rightsquigarrow I^*$
$\forall I'(j_\sigma \rightsquigarrow I' \multimap H'' \rightsquigarrow S''(I'))$
$\multimap H'' \rightsquigarrow \mathbf{a}(\lambda J[J \subseteq I \wedge \text{MONDAY}(J)], \lambda I[S''(I)])\ ).$

Next, combining (67) and (68) using substitution

$$[H'' \mapsto (f_\sigma \text{ PRESTR}), I \mapsto I^*, S'' \mapsto \textbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)], \lambda Y_2[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y_2)(J)])])\ ]$$

yields

(69) $\forall I^* \forall J(\ (f_\sigma \text{ EVAR}) \rightsquigarrow J \otimes (j_\sigma \text{ TOI}) \rightsquigarrow I^*$
$\multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow \mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\lambda I[\textbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)],$
$\lambda Y_2[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y_2)(J)])])\ ).$

At this stage, the **a** from the TPP is already seen to scope over the **every** from the object. Next, (69) is combined with the determination axiom using substitution

$$[R \mapsto \mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')], \lambda I[\textbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)], \lambda Y_2[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y_2)(J)])])\ ]$$

and then with the finalization axiom, and ending with quantifier simplification, we get (70) as the outcome of the first derivation.

(70) $\forall I^*(\ (f_\sigma \text{ TOI}) \rightsquigarrow I^*$
$\multimap \exists J[\mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\lambda I[\textbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)],$
$\lambda Y_2[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y_2)(J)])])]\ ).$

This represents the reading in which the determination quantifier (**a**) has highest scope, then the TPP-quantifier (**a**), and the object quantifier (**every**) has lowest scope.

To interchange scopes between the TPP quantifier (**a**) and the object quantifier (**every**), the derivation proceeds as follows. First, (29), the meaning of Mary interviewed, is derived as before. However, instead of directly combining it with the subject meaning, it is first combined with (68) (itself derived as before), using substitution

$$[H'' \mapsto (f_\sigma \text{ PRESTR}), I \mapsto I^*, S'' \mapsto \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)]\ ]$$

yielding

(71) $\forall I^* \forall J(\ (f_\sigma \text{ EVAR}) \rightsquigarrow J \otimes (j_\sigma \text{ TOI}) \rightsquigarrow I^* \otimes h_\sigma \rightsquigarrow Y$
$\quad\multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow \mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\quad\quad \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)])\ ).$

Now, (71) is combined with the determination axiom (17) using substitution

$$[I \mapsto I^*, R \mapsto \mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')], \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)])\ ]$$

to yield (72).

(72) $\forall H \forall S \forall I^*(\ (f_\sigma \text{ TOI}) \rightsquigarrow I^* \otimes h_\sigma \rightsquigarrow Y$
$\quad \otimes \forall I'(f_\sigma \rightsquigarrow I' \multimap H \rightsquigarrow S(I'))$
$\quad \multimap H \rightsquigarrow \mathbf{a}(\lambda J[\mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\quad\quad \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)])], S)\ ).$

At this point, (72) is combined with the object meaning (28) using substitution

$$[X \mapsto Y, H' \mapsto H, S' \mapsto \mathbf{a}(\lambda J[\mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')], \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)])], S))\ ]$$

yielding (73).

(73) $\forall H \forall S \forall I^*(\ (f_\sigma \text{ TOI}) \rightsquigarrow I^*$
$\quad \otimes \forall I'(f_\sigma \rightsquigarrow I' \multimap H \rightsquigarrow S(I'))$
$\quad \multimap H \rightsquigarrow \mathbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)],$
$\quad\quad \lambda Y_2[\mathbf{a}(\lambda J[\mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\quad\quad\quad \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)])], S)\ ),$

which, after combining with the finalization axiom ans simplifying the quantifier, yields (74), the reading with **every** having the highest scope.

(74) $\forall I^*(\ (f_\sigma \text{ TOI}) \rightsquigarrow I^*$
$\quad \multimap df_\sigma \rightsquigarrow \mathbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)],$
$\quad\quad \lambda Y_2[\exists J[\mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\quad\quad\quad \lambda I[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)])]])\ ).$

Finally, to derive the third reading (of multiple interviewing events in one Monday), the order of combination is as follows (where most details are suppressed). First, (29) is combined with the determination axiom, the result being combined with object meaning (28), and the result of that is combined with the TPP-meaning (68). After combining with the finalization axion, we get as the end result (75).

(75) $\forall I^*(\ (f_\sigma \text{ TOI}) \rightsquigarrow I^*$
$\quad \multimap df_\sigma \rightsquigarrow \mathbf{a}(\lambda J'[J' \subseteq I^* \wedge \text{MONDAY}(J')],$
$\quad\quad \lambda I[\mathbf{every}(\lambda Y_1[\text{STUDENT}(Y_1)],$
$\quad\quad\quad \lambda Y_2[\exists J[J \subseteq I \wedge \text{INTERVIEW}(\text{MARY}, Y)(J)]])])\ ).$

There is a natural correlation between the order of combination with axioms and the order of pseudo-applications in the functional syntax-semantics interface in ([7]).

A point to notice at this stage is that, as is known, there is no proper account in the glue-language approach to blocking meanings that are inaccessible due to word ordering. This matter is currently under investigation (Mary Darlymple - private communication). For example, in (76) the "collective-event" reading seems to be inaccessible:

(76) On Monday, Mary interviewed every student

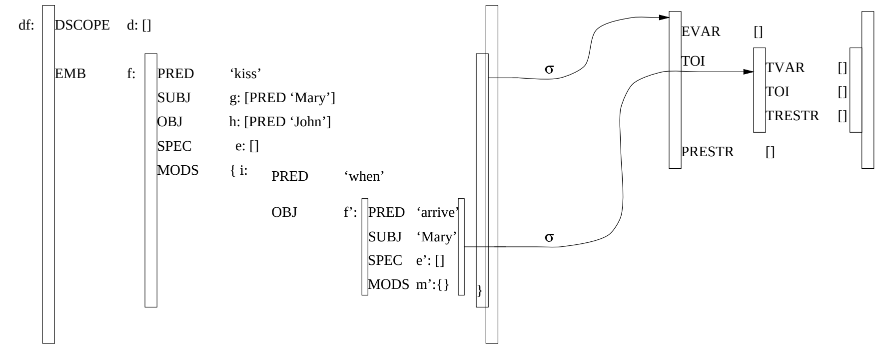

Figure 7: The f-structure and f_σ-structure for Mary kissed John when she arrived

Since the f-structure (and its projection) are the same for this preposed-TPP sentence as for its non-preposed counterpart, the same meaning-assembly axioms are induced, and the same meanings are derivable. It is expected that a general solution to to word-order effects in an LFG framework will solve also the problem of blocking unavailable meaning derivations for preposed TPPs.

5 Sentential prepositional complements

We now turn to derivations of meaning of temporally modified sentences in which the TPP consists of a temporal preposition complemented with a sentence (instead of a TNP in the previous sections). It is here that the similarity in type between the meaning of a TNP and the meaning of a sentence, both being GTQs, is exploited. We exemplify the derivation method by deriving the meaning of (77), suppressing the way the anaphoric she is resolved to Mary.

(77) Mary kissed John when she arrived.

The f-structure of (77) and its semantic projection are shown in Figure 7.

Note that here the f-structure f' of Mary arrived is properly embedded within the f-structure f of Mary kissed John, and not within a dummy f-structure, as would be the case if the stand-alone meaning of Mary arrived had been the goal. Note also the identification, within the semantic projection, of (f_σ TOI) with f'_σ, similar to the previous identification for TNP-complemented TPPs in Figures 3-6. We do not repeat here the whole repertoire of meaning assembly axioms, which can be worked out similarly to previous examples. Note, however, that there are two copies of the determination meaning-assembly axiom, one contributed by the main clause and the other - by the subordinate clause. In addition, the temporal preposition when is taken here not to contribute[9] any meaning-assembly axiom.

First, we can derive (20) (repeated here as (78)),

(78) $\forall I \forall J(\ (f_\sigma\ \mathrm{EVAR}) \rightsquigarrow J \otimes (f_\sigma\ \mathrm{TOI}) \rightsquigarrow I$
$\qquad \multimap\ (f_\sigma\ \mathrm{PRESTR}) \rightsquigarrow (J \subseteq I \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J))\ ).$

In addition, we can derive as before the meaning (79) of Mary arrived (using the appropriate copy of the determination axiom), and with the apropriate renaming of f-structure components.

(79) $\forall H \forall S \forall I(\ (f'_\sigma\ \mathrm{TOI}) \rightsquigarrow I$
$\qquad \otimes \forall I'(f'_\sigma \rightsquigarrow I' \multimap H \rightsquigarrow S(I'))$
$\qquad \multimap H \rightsquigarrow \mathbf{the}(\lambda J[J \subseteq I \wedge \textsc{arrive}(\textsc{mary})(J)], S)\ ).$

[9]There is a vast literature on the lexical semantics of when. In some of its other uses, it may contribute a meaning-assembly axiom of its own.

In view of $(f_\sigma \text{ TOI}) \equiv f'_\sigma$, we now can combine (78) with (79), using the substitution

$$[\ S \mapsto J \subseteq I \wedge \textsc{kiss}(\textsc{mary}, \textsc{john})(J), H \mapsto (f_\sigma \text{ PRESTR})\ ]$$

to obtain

(80) $\forall I \forall J(\ (f'_\sigma \text{ TOI}) \rightsquigarrow I\ \otimes (f_\sigma \text{ EVAR}) \rightsquigarrow J$
$\multimap (f_\sigma \text{ PRESTR}) \rightsquigarrow \mathbf{the}(\lambda J'[J' \subseteq I \wedge \textsc{arrive}(\textsc{mary})(J')], \lambda I'[J \subseteq I' \wedge \textsc{kiss}(\textsc{Mary}, \textsc{John}(J)])).$

This derivation-step embodies the role of the meaning of Mary kissed John as the scope of the "hidden" determination quantifier in the meaning of embedded sentence Mary arrived. From here on the derivation proceeds as before, as there is no difference whether (80) has been derived from a TNP prepositional complement or sentential prepositional complement; they look the same. Using the second copy of the determination axiom and the finalization axiom (with appropriate substitutions), we obtain (81) as the meaning of (77).

(81) $\forall I(\ (f_\sigma \text{ TOI}) \rightsquigarrow I \multimap df_\sigma \rightsquigarrow \exists J[\mathbf{the}(\ \lambda J'[J' \subseteq I \wedge \textsc{arrive}(\textsc{mary})(J')],$
$\lambda I'[J \subseteq I' \wedge \textsc{kiss}(\textsc{Mary}, \textsc{John}(J)])]\ ).$

Note that another potential derivation, in which (78) is prematurly combined with the second copy of the determination axiom, leads to a blind alley. The two determined meanings of the two clauses cannot be combined. This partial derivation is ruled out by the linearity of LL.

6 Conclusion

In this paper, we have presented an account of the semantics of English temporal preposition phrases as temporal generalized quantifiers, using the glue-language deductive approach as developed in the LFG framework. We focused our attention on temporal preposition phrases whose noun-phrase complements contain quantifying determiners or sentences. A similar account can be given for TPPS that modify TNs within another TPP. We departed from previous accounts using the glue-language approach in attributing meaning-assembly axioms directly to f-structures, instead of lexical components of the interpreted phrase. Certain contributors of axioms are not syntactically realized, and certain ambiguities cannot be explained solely in terms of the lexical components. A central advantage of the glue-language approach we identify is the ability to directly access components of meaning representations in any convenient order. This contrasts with the strict ordering of λ-bound variables in a λ-expression, which restricts the order of possible β-reductions.

An issue left open is how to account for the effect of temporal modification by means of TPPs on the interpretation of TNPs in argument position. For example, in

(82) Mary hated every meeting in January

the TPP in January has a double role: it modifes the time of hating, restricting it to January; in addition, it restricts the scope of quantification of the universal quantifier to meetings in January, not every meeting in the world. Some unification technique, unifying two I-arguments, seem to be called for. We leave it for further research.

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