

## Modularity and compositionality: The case of temporal modifiers \*

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**Abstract** This paper concerns the possibility of building Montague grammars in a modular and incremental way. As an illustration, we investigate the following question: Given an *atemporal* Montague grammar, on the one hand, and a temporal ontology, on the other hand, is it possible to combine them into a new grammar such that it would: (i) conservatively extend the original grammar, and (ii) allow temporal modifiers to be accommodated?

**Keywords:** compositionality, modularity, temporal prepositional phrases

### 1 Introduction

One says that a semantics is compositional when it allows the meaning of a complex expression to be computed from the meaning of its constituents. One also says that a system is modular if it is made of relatively independent components. In the case of a semantic system, say a Montague grammar, we will say that it is modular if the ontology on which it is based (including notions such as *truth*, *entities*, *events*, *possible worlds*, *time intervals*, *state of knowledge*, *state of believe*, ...) is obtained by combining relatively independent simple ontologies.

We believe that modularity is a requirement as important as compositionality. A large semantic system that is not be modular would be quite difficult to grasp and present little explanatory power. In addition, modularity plays an essential part in the incremental development of a semantic system. Typically, in the absence of modularity, when studying a new semantic phenomenon, it is problematic to decide whether and how the proposed treatment is compatible with the treatments of other phenomena.

This paper may be seen as an exercise in developing a modular semantic system. As a case of study, we consider the temporal modifiers. The question we want to investigate is then the following. Given an *atemporal* Montague grammar, on the one hand, and a temporal ontology, on the other hand, is it possible to combine them into a new grammar such that it would:

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- i. conservatively extend the original grammar;
- ii. allow temporal modifiers to be accommodated.

This question is not as easy as it might seem at first sight. Temporal modifiers, indeed, may be cascaded, which interacts in a non-trivial way with quantification and binding. This is illustrated by the following sentence, taken from [Pratt & Francez 2001](#), where the existentially quantified modifier *one Monday* determines the quantification domain of the universally quantified modifier *during every meeting*:

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

A classical account of temporal modification has been given by [Dowty 1979, 1982](#). As with most such accounts,<sup>1</sup> it is based on an interpretation of sentences as sets of time intervals,<sup>2</sup> which seems unavoidable in order to interpret cascades of temporal modifiers. Consider, for instance, the following sentence ([Dowty 1982](#)):

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

For such a sentence, where the cascaded temporal modifiers are existentially quantified, Dowty's theory makes the correct prediction. This is not the case, however, for sentences akin to (1), as it was first observed by [Pratt & Francez 2001](#).

In fact, every treatment of quantified temporal prepositional phrases prior to [Pratt & Francez 2001](#) fails in making correct predictions for sentences akin to (1).<sup>3</sup> For this reason, the treatment we are proposing in this paper may be partly seen as a reengineering of Pratt and Francez's solution.

Their analysis of example (1) works as follows. The sentence *Mary kissed John* is assigned the following meaning:

(3)  $\llbracket \textit{Mary kissed John} \rrbracket = \lambda i. \exists e. (\mathbf{kissed} \mathbf{m} \mathbf{j} e) \wedge ((\tau e) \subset i)$ ,

where  $i$  denotes a time interval,  $e$  denotes an event, and  $\tau$  maps an event to the time interval during which it occurs. In a similar way, the noun *meeting* is assigned meaning (4), while the determiner *every* is assigned its standard meaning:

(4)  $\llbracket \textit{meeting} \rrbracket = \lambda xi. (\mathbf{meeting} x) \wedge ((\tau x) \subset i)$ ,

(5)  $\llbracket \textit{every} \rrbracket = \lambda pq. \forall x. (px) \rightarrow (qx)$ .

Since the interpretation of *meeting* is a relation between (event-like) entities and time intervals, applying to it the interpretation of *every* would result in a type mismatch. To circumvent this problem, an operation called pseudo-application is defined:

1 In addition to [Dowty 1979, 1982](#), see [Pratt & Francez 2001](#); [Francez & Steedman 2006](#); [von Stechow 2002, 2009](#)

2 Or, possibly, sets of pairs of time intervals, as it is the case in [Dowty 1982](#).

3 See [Pratt & Francez 2001](#), for a discussion.

$$(6) \quad \phi ({}_1\psi)_1 = \lambda qi. \phi (\lambda x. \psi xi) q.$$

This allows the meaning of the noun phrase *every meeting* to be computed as follows:

$$\begin{aligned} (7) \quad \llbracket \textit{every meeting} \rrbracket &= \llbracket \textit{every} \rrbracket ({}_1\llbracket \textit{meeting} \rrbracket)_1 \\ &= \lambda qi. \llbracket \textit{every} \rrbracket (\lambda x. \llbracket \textit{meeting} \rrbracket xi) q \\ &= \lambda qi. (\lambda pq. \forall x. (px) \rightarrow (qx)) (\lambda x. \llbracket \textit{meeting} \rrbracket xi) q \\ &\rightarrow_{\beta} \lambda qi. \forall x. (\llbracket \textit{meeting} \rrbracket xi) \rightarrow (qx) \\ &\rightarrow_{\beta} \lambda qi. \forall x. ((\mathbf{meeting}x) \wedge ((\tau x) \subset i)) \rightarrow (qx). \end{aligned}$$

As for the preposition *during*, Pratt and Francez assign it the following interpretation:

$$(8) \quad \llbracket \textit{during} \rrbracket = \lambda pqi. p(\lambda x. q(\tau x))i.$$

Then, by applying (8) to (7), one obtains the interpretation of the prepositional phrase *during every meeting*:

$$(9) \quad \llbracket \textit{during every meeting} \rrbracket = \lambda qi. \forall x. ((\mathbf{meeting}x) \wedge ((\tau x) \subset i)) \rightarrow (q(\tau x)).$$

The meaning of *(during) one monday* is computed in similar way, which yields the following result:

$$(10) \quad \llbracket (\textit{during}) \textit{one monday} \rrbracket = \lambda qi. \exists x. (\mathbf{monday}x) \wedge ((\tau x) \subset i) \wedge (q(\tau x)).$$

Finally, by applying (9) to (3), and then applying (10) to the result, one obtains the following reading for sentence (1):

$$\begin{aligned} (11) \quad \lambda i. \exists x. (\mathbf{monday}x) \wedge ((\tau x) \subset i) \wedge \\ (\forall y. ((\mathbf{meeting}y) \wedge ((\tau y) \subset (\tau x))) \rightarrow \\ (\exists e. (\mathbf{kissed} \mathbf{m} \mathbf{j} e) \wedge ((\tau e) \subset (\tau y))))). \end{aligned}$$

Pratt and Francez's analysis has certainly the merit of making the right prediction, in the sense that formula (11) captures the intuitive truth conditions of sentence (1). Nevertheless, there are some oddities in their solution, which prevent it from being modular:

- i. Their analysis does not rely on any precise notion of syntax-semantics interface. Consequently, the compositional way of computing the meaning of a sentence is not completely specified.<sup>4</sup>
- ii. Sentences are sometimes interpreted as truth values, sometimes as sets of time intervals, and even sometimes as relations between events and time

<sup>4</sup> This is not a serious objection since Francez & Steedman 2006 recasts the solution in the fully specified framework of Combinatory Categorical Grammars.

intervals. In other words, there is no notion of proposition that allows the sentences to be interpreted in a uniform way. As a consequence, the compositionality of their semantics relies on non standard operations such as the so-called pseudo-applications.

- iii. The fact that the subinterval relations occurring in formula (11) are not contributed by the meaning assigned to *during* goes against the intuition. As a consequence, the interpretation of *during* in (8) is rather opaque. (von Stechow 2002 makes a similar criticism.)
- iv. There is no uniform treatment of the temporal prepositions. In particular, the meaning assigned to prepositions such as *before* and *after* relies on quite ad hoc primitives, the existence of which may appear as a constraint on the temporal ontology. (Again, von Stechow 2002 makes a similar criticism.)
- v. Their solution is bound to event semantics in an essential way. Indeed, the use of the operator  $\tau$  is central to their solution. It allows them to quantify over time intervals by quantifying over events.<sup>5</sup>

In the rest of this paper, we will try to circumvent all these possible drawbacks.

## 2 The syntax semantics interface

As explained in the preceding introduction, we intend to sketch a semantic interpretation of temporal prepositional phrases that is both compositional and modular. To this end, we will stick to a strict Montagovian framework, i.e., we will construct the semantic interpretation as a homomorphic image of the syntax. We do not want, however, to commit ourselves to some precise syntactic theory. Accordingly, we will consider that meanings are computed from abstract syntactic structures that correspond to plausible logical forms. Technically, these abstract structures (or logical forms) will be represented as typed  $\lambda$ -terms built upon a given signature. Consider, for instance, the following sentence:

(12) Every professor kissed a student.

Its logical form is expressed by the following  $\lambda$ -term, which is built upon the signature given in Table 1:

(13)  $\text{KISSED}(\text{SOME STUDENT})(\text{EVERY PROFESSOR})$ .

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<sup>5</sup> This will not appear as a problem to those who like to work in a Davidsonian framework, but it may be seen as quite a constraint by the others.

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JOHN : $NP$
MARY : $NP$
PROFESSOR : $N$
STUDENT : $N$
MEETING : $N$
MONDAY : $N$
SOME : $N \rightarrow NP$
EVERY : $N \rightarrow NP$
KISSED : $NP \rightarrow NP \rightarrow S$

**Table 1** The signature specifying the abstract syntactic structure

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Expression (13) is a purely applicative term that may be seen as a tree. This is not the general case. Logical forms may possibly involve  $\lambda$ -abstractions. For instance, we could enrich the signature of Table 1 with the following constant:

$$QR : NP \rightarrow (NP \rightarrow S) \rightarrow S,$$

and write the following  $\lambda$ -term:

$$QR(\text{SOME STUDENT})(\lambda x. \text{KISSED } x(\text{EVERY PROFESSOR})),$$

which would correspond to the object wide-scope reading of sentence (12).

Having specified the source of our semantic interpretation, we must specify its target. Here we follow an architecture similar to Montague 1973. We assume the existence of an intermediate language which allows meanings to be expressed as logical formulas. This object language consists of the simply typed  $\lambda$ -calculus enriched with the connectives and quantifiers of first-order logic, and specific relational symbols (given in their Curryfied form). Table 2 gives a signature that specifies such relational symbols.

Finally, the semantic interpretation itself is specified by assigning a term of the object language to each constant of the signature specifying the abstract syntactic structures. This interpretation must, of course, respect some typing constraints that ensure that the semantic interpretation of the syntactic categories is consistent. Table 3, where  $e^*$  stands for  $(e \rightarrow t) \rightarrow t$ , gives such an interpretation, which corresponds fairly to a standard Montagovian semantics. It allows the meaning of a sentence such as (12) to be computed as follows: replace, in the abstract syntactic structure (13), each constant by its interpretation (as given by Table 3), then  $\beta$ -normalize the resulting  $\lambda$ -term.

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<b>j</b> : e
<b>m</b> : e
<b>professor</b> : e → t
<b>student</b> : e → t
<b>meeting</b> : e → t
<b>monday</b> : e → t
<b>kissed</b> : e → e → t

**Table 2** The signature providing the relational symbols of the object language

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JOHN := $\lambda k.k\mathbf{j}$	: e*
MARY := $\lambda k.k\mathbf{m}$	: e*
PROFESSOR := $\lambda x.\mathbf{professor}x$	: e → t
STUDENT := $\lambda x.\mathbf{student}x$	: e → t
MEETING := $\lambda x.\mathbf{meeting}x$	: e → t
MONDAY := $\lambda x.\mathbf{monday}x$	: e → t
SOME := $\lambda pq.\exists x.(px) \wedge (qx)$	: (e → t) → e*
EVERY := $\lambda pq.\forall x.(px) \rightarrow (qx)$	: (e → t) → e*
KISSED := $\lambda os.s(\lambda x.o(\lambda y.\mathbf{kissed}xy))$	: e* → e* → t

**Table 3** The semantic interpretation

Table 1, 2, and 3 will be used as a running example in the rest of this paper. They correspond to our original grammar, i.e., the *atemporal* Montague grammar that we want to extend to the end of accommodating temporal modifiers

### 3 The temporal ontology

In search of a generic treatment of temporal modification, we must impose as few requirements as possible on the temporal ontology. Basically, we require the existence of a partial order  $(\mathbb{I}, \subset)$ . The elements of  $\mathbb{I}$  are thought of as time intervals, and the binary relation  $\subset$  as time interval inclusion.

Then, in order to accommodate temporal preposition such as *before*, *after*, or *until*, one may require some additional structure on  $\mathbb{I}$ . For instance, we may need to provide the set of time intervals with a precedence relation,  $<$ . Typically,  $\mathbb{I}$  may be the set of closed intervals obtained from a linearly ordered set, as it is the case in standard interval temporal logic (Halpern & Shoham 1991). In such a case, the

temporal relations under consideration may be the twelve interval relations of [Allen 1983](#). Such a commitment to a given temporal logic, however, is not mandatory. One may think of  $\mathbb{I}$  as a set of abstract intervals, provided with some binary relations obeying some given laws. For instance, one would require both the inclusion and precedence relations to be partial orders obeying, in addition, the following laws:

$$\begin{aligned} (i \subset j) &\leftrightarrow \neg(i < j), \\ (i \subset j) &\leftrightarrow \neg(j < i), \\ ((i \subset j) \wedge (j < k)) &\rightarrow (i < k), \\ ((i < j) \wedge (k < j)) &\rightarrow (i < k). \end{aligned}$$

To reflect the existence of the temporal structure at the level of the object language, we add a new type,  $i$ , which will be semantically interpreted as  $\mathbb{I}$ . This allows new logical connectives to be defined. Typically, the during-modality is defined as follows:

$$(14) \quad \langle D \rangle \phi = \lambda i. \exists j. (j \subset i) \wedge (\phi j).$$

Its dual, which will play a part in [Section 5](#), is then defined accordingly:

$$(15) \quad [D] \phi = \lambda i. \forall j. (j \subset i) \rightarrow (\phi j).$$

Similarly, one defines the before-modalities as follows:<sup>6</sup>

$$(16) \quad \langle B \rangle \phi = \lambda i. \exists j. (j < i) \wedge (\phi j),$$

$$(17) \quad [B] \phi = \lambda i. \forall j. (j < i) \rightarrow (\phi j).$$

#### 4 The temporalization procedure

Having chosen an adequate temporal ontology, the next step is to provide our original grammar with a temporal dimension. To this end, we take

$$\text{prop} = i \rightarrow t$$

to be type of the propositions, and we applied a systematic *temporalization procedure* akin to the intentionalization procedure defined in [de Groote & Kanazawa 2013](#).

De Groote and Kanazawa's intentionalization procedure provides a systematic way of turning an extensional semantics into an intensionalized one without changing the truth conditions of the sentences. It is defined in a higher-order setting. Instantiating it to the case of first-order logic amounts simply to giving appropriate translation for the relational symbols and for the logical connectives and quantifiers.

<sup>6</sup> In [Halpern & Shoham 1991](#), the “before” modalities are written as  $\langle \bar{L} \rangle$  and  $[\bar{L}]$ , where  $L$  stands for the “later” relation, and  $\bar{L}$  for its inverse. As for  $B$ , it denotes the “begins” relation.

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<b>t_professor</b>	: e → i → t
<b>t_student</b>	: e → i → t
<b>t_meeting</b>	: e → i → t
<b>t_monday</b>	: e → i → t
<b>t_kissed</b>	: e → e → i → t

**Table 4** The new object signature

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Let us define such a translation, which we will write as  $[-]_1$ . For the relational symbols, we simply add a temporal parameter to each of them by changing the object signature. For our running example, this results in the new object signature given in Table 4.

Each relational symbol is then translated into the new corresponding symbol. For instance, we have:

$$[\mathbf{professor}]_1 = \mathbf{t\_professor}.$$

As for the translation of the logical connectives and quantifiers, it is straightforward:

$$\begin{aligned} [\circ]_1 &= \lambda abi. (ai) \circ (bi), \quad \circ \in \{\wedge, \rightarrow\}, \\ [\mathbf{Q}]_1 &= \lambda pi. \mathbf{Q}(\lambda x. pxi), \quad \mathbf{Q} \in \{\exists, \forall\}. \end{aligned}$$

Finally, the translation is homomorphically extended to the  $\lambda$ -terms:<sup>7</sup>

$$\begin{aligned} [x]_1 &= x, \\ [\lambda x. t]_1 &= \lambda x. [t]_1, \\ [tu]_1 &= [t]_1 [u]_1. \end{aligned}$$

Now consider an *atemporal* model  $\mathfrak{M}_0$ , a *temporal* model  $\mathfrak{M}_1$ , and a time interval  $i_0 \in \mathbb{I}$  (intuitively the time interval of reference) such that:

$$\mathfrak{M}_0 \models \mathbf{r}t_1 \cdots t_n \text{ iff } \mathfrak{M}_1 \models \mathbf{t\_r}t_1 \cdots t_n i_0,$$

for every  $n$ -ary relational symbol  $\mathbf{r}$ . One easily establishes, by a straightforward induction, that

$$\mathfrak{M}_0 \models \phi \text{ iff } \mathfrak{M}_1 \models [\phi]_1 i_0.$$

Let us use boldface symbols ( $\wedge, \exists, \dots$ ) to denote the translations of the logical connectives and quantifiers, let us write  $[-]$  for  $[-]_1$ , and let us define  $e^*$  to be

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<sup>7</sup> It should be clear that this allows for the translation of the formulas, which are seen as pure  $\lambda$ -terms. For instance, the formula  $\forall x. a[x] \wedge b[x]$  stands for a  $\lambda$ -term akin to **all** ( $\lambda x. \mathbf{and}(ax)(bx)$ ).



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JOHN := $\lambda k.k\mathbf{j}$	: $e^*$
MARY := $\lambda k.k\mathbf{m}$	: $e^*$
PROFESSOR := $\lambda x.[\mathbf{professor}]x$	: $e \rightarrow \text{prop}$
STUDENT := $\lambda x.[\mathbf{student}]x$	: $e \rightarrow \text{prop}$
MEETING := $\lambda x.[\mathbf{meeting}]x$	: $e \rightarrow \text{prop}$
MONDAY := $\lambda x.[\mathbf{monday}]x$	: $e \rightarrow \text{prop}$
SOME := $\lambda pq.\exists x.(px) \wedge (qx)$	: $(e \rightarrow \text{prop}) \rightarrow e^*$
EVERY := $\lambda pq.\forall x.(px) \rightarrow (qx)$	: $(e \rightarrow \text{prop}) \rightarrow e^*$
KISSED := $\lambda os.s(\lambda x.o(\lambda y.[\mathbf{kissed}]xy))$	: $e^* \rightarrow e^* \rightarrow \text{prop}$

**Table 5** The new semantic interpretation

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$(e \rightarrow \text{prop}) \rightarrow \text{prop}$ . Then, applying our temporalization procedure to the original grammar, we obtain the new semantic interpretation given in Table 5. It is then clear, at first sight, that this new interpretation is in all respects similar to the original one.

## 5 Accommodating temporal prepositions

We are now in a position to enrich our original grammar with temporal items. Consider the preposition *during*. At the level of the abstract syntactic structures, it gives rise to the following typed constant:

$$(18) \quad \text{DURING} : NP \rightarrow S \rightarrow S.$$

In temporal logic, *b during a* is expressed as  $a \wedge \langle D \rangle b$ . This suggests the following semantic interpretation:

$$(19) \quad \text{DURING} := \lambda ns.n(\lambda x.\langle D \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}.$$

Let us now use interpretation (19) to compute the semantic interpretation of the following examples:

- (20) Mary kissed John during some meeting.
- (21) Mary kissed John during some meeting one Monday.
- (22) Mary kissed John during every meeting.
- (23) Mary kissed John during every meeting one Monday.

The interpretation of example (20), which is computed as follows, produces the expected reading:

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$$\begin{aligned} & \text{DURING (SOME MEETING) (KISSED JOHN MARY)} \\ & \rightarrow_{\beta} \exists x. ([\text{meeting}]x) \wedge \langle D \rangle ([\text{kissed}] \mathbf{m} \mathbf{j}) \\ & \rightarrow_{\beta} \lambda i. \exists x. (\mathbf{t\_meeting} x i) \wedge (\exists j. (j \subset i) \wedge (\mathbf{t\_kissed} \mathbf{m} \mathbf{j} j)). \end{aligned}$$

The interpretation of example (21), which is computed in a similar way, illustrates how our system accounts for cascades of temporal modifiers:

$$\begin{aligned} & \text{DURING (SOME MONDAY) (DURING (SOME MEETING) (KISSED JOHN MARY))} \\ & \rightarrow_{\beta} \exists x. ([\text{monday}]x) \wedge \langle D \rangle (\exists y. ([\text{meeting}]y) \wedge \langle D \rangle ([\text{kissed}] \mathbf{m} \mathbf{j})) \\ & \rightarrow_{\beta} \lambda i. \exists x. (\mathbf{t\_monday} x i) \wedge \\ & \quad (\exists j. (j \subset i) \wedge (\exists y. (\mathbf{t\_meeting} y j) \wedge (\exists k. (k \subset j) \wedge (\mathbf{t\_kissed} \mathbf{m} \mathbf{j} k)))). \end{aligned}$$

Example (22), which involves a universal quantification, is more interesting. Computing its interpretation yields a reading that may seem odd at first sight:

$$\begin{aligned} & \text{DURING (EVERY MEETING) (KISSED JOHN MARY)} \\ & \rightarrow_{\beta} \forall x. ([\text{meeting}]x) \rightarrow \langle D \rangle ([\text{kissed}] \mathbf{m} \mathbf{j}) \\ & \rightarrow_{\beta} \lambda i. \forall x. (\mathbf{t\_meeting} x i) \rightarrow (\exists j. (j \subset i) \wedge (\mathbf{t\_kissed} \mathbf{m} \mathbf{j} j)). \end{aligned}$$

In fact, the above formula captures correctly the intuitive truth conditions of sentence (22) if we interpret it under a universal closure.

This need for a universal closure explains why our system (in its current state) fails in making a correct prediction in the case of sentence (23). Indeed, the following computation yields a reading which is clearly wrong:<sup>8</sup>

$$\begin{aligned} & \text{DURING (SOME MONDAY) (DURING (EVERY MEETING) (KISSED JOHN MARY))} \\ & \rightarrow_{\beta} \exists x. ([\text{monday}]x) \wedge \langle D \rangle (\forall y. ([\text{meeting}]y) \rightarrow \langle D \rangle ([\text{kissed}] \mathbf{m} \mathbf{j})) \\ & \rightarrow_{\beta} \lambda i. \exists x. (\mathbf{t\_monday} x i) \wedge \\ & \quad (\exists j. (j \subset i) \wedge (\forall y. (\mathbf{t\_meeting} y j) \rightarrow (\exists k. (k \subset j) \wedge (\mathbf{t\_kissed} \mathbf{m} \mathbf{j} k)))). \end{aligned}$$

In fact, the above formula (as it appears on the second line of the computation) would correctly capture the truth conditions of sentence (23) if the first occurrence of  $\langle D \rangle$  was replaced by  $[D]$ . This means that, according to the quantificational context, *during* must sometimes be interpreted as  $\lambda ns.n(\lambda x.[D]s)$ . Knowing when one should use one modality or the other (i.e.,  $\langle D \rangle$  or  $[D]$ ) can be easily computed with a simple polarity calculus that we may incorporate in our type discipline. To this end, we replace the signature given in Table 1 by the one given in Table 6. The semantic interpretation of the new polarized items is then as given by Table 7.

<sup>8</sup> This wrong reading is reminiscent of the one that would be obtained if one would use the semantic interpretation given by Dowty 1982.

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JOHN : $NP$
MARY : $NP$
PROFESSOR : $N$
STUDENT : $N$
MEETING : $N$
MONDAY : $N$
SOME : $N \rightarrow NP$
SOME <sup>+</sup> : $N \rightarrow NP^+$
EVERY : $N \rightarrow NP$
EVERY <sup>-</sup> : $N \rightarrow NP^-$
KISSED : $NP \rightarrow NP \rightarrow S^+$
DURING <sup>++</sup> : $NP^+ \rightarrow S^+ \rightarrow S^+$
DURING <sup>+-</sup> : $NP^+ \rightarrow S^- \rightarrow S^+$
DURING <sup>-+</sup> : $NP^- \rightarrow S^+ \rightarrow S^-$
DURING <sup>--</sup> : $NP^- \rightarrow S^- \rightarrow S^-$

**Table 6** The polarized signature

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The use of polarized items constrains the logical form of sentence (23) to be the following:

$$\text{DURING}^{+-}(\text{SOME}^+ \text{ MONDAY})(\text{DURING}^{-+}(\text{EVERY}^- \text{ MEETING})(\text{KISSED JOHN MARY})).$$

Then, computing the semantic interpretation of sentence (23) from the preceding logical form yields the expected result:

$$\begin{aligned} & \text{DURING}^{+-}(\text{SOME}^+ \text{ MONDAY})(\text{DURING}^{-+}(\text{EVERY}^- \text{ MEETING})(\text{KISSED JOHN MARY})) \\ & \rightarrow_{\beta} \exists x. ([\text{monday}]x) \wedge [D](\forall y. ([\text{meeting}]y) \rightarrow \langle D \rangle([\text{kissed}]mj)) \\ & \rightarrow_{\beta} \lambda i. \exists x. (\mathbf{t\_monday} xi) \wedge \\ & \quad (\forall j. (j \subset i) \rightarrow (\forall y. (\mathbf{t\_meeting} y j) \rightarrow (\exists k. (k \subset j) \wedge (\mathbf{t\_kissed} mj k))))). \end{aligned}$$

## 6 Adding a deictic dimension

Our analysis of the preposition *during* suggests that a similar treatment may be applied to other temporal prepositions. In the case of the preposition *before*, it would

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$\text{SOME}^+ := \lambda pq. \exists x. (px) \wedge (qx)$	$: (e \rightarrow \text{prop}) \rightarrow e^*$
$\text{EVERY}^- := \lambda pq. \forall x. (px) \rightarrow (qx)$	$: (e \rightarrow \text{prop}) \rightarrow e^*$
$\text{DURING}^{++} := \lambda ns. n(\lambda x. \langle D \rangle s)$	$: e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{DURING}^{+-} := \lambda ns. n(\lambda x. [D] s)$	$: e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{DURING}^{-+} := \lambda ns. n(\lambda x. \langle D \rangle s)$	$: e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{DURING}^{--} := \lambda ns. n(\lambda x. [D] s)$	$: e^* \rightarrow \text{prop} \rightarrow \text{prop}$

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**Table 7** Semantic interpretation of the polarized items

amount to enrich our system with the following items:

$$\begin{aligned} \text{BEFORE}^{++} &:= \lambda ns. n(\lambda x. \langle B \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}, \\ \text{BEFORE}^{+-} &:= \lambda ns. n(\lambda x. [B] s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}, \\ \text{BEFORE}^{-+} &:= \lambda ns. n(\lambda x. \langle B \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}, \\ \text{BEFORE}^{--} &:= \lambda ns. n(\lambda x. [B] s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}. \end{aligned}$$

Let us use these new items to compute the semantic interpretation of the following sentence:

(24) *Mary kissed John before some meeting one Monday.*

This yields the following result:

$$\begin{aligned} &\text{DURING}^{++}(\text{SOME}^+ \text{MONDAY})(\text{BEFORE}^{++}(\text{SOME}^+ \text{MEETING})(\text{KISSED JOHN MARY})) \\ &\rightarrow_{\beta} \exists x. ([\text{monday}]x) \wedge \langle D \rangle (\exists y. ([\text{meeting}]y) \wedge \langle B \rangle ([\text{kissed}] \mathbf{m j})) \\ &\rightarrow_{\beta} \lambda i. \exists x. (\mathbf{t\_monday} x i) \wedge \\ &\quad (\exists j. (j \subset i) \wedge (\exists y. (\mathbf{t\_meeting} y j) \wedge (\exists k. (k < j) \wedge (\mathbf{t\_kissed} \mathbf{m j k}))))). \end{aligned}$$

The above formula does not completely capture the meaning of sentence (24). It correctly predicts that *there is a monday during which some meeting takes place*. It also predicts that *there is some kissing event that happens before the meeting*. But it does not predict that *the kissing event happens on that monday*.

To circumvent this problem, we must provide our interpretation with an additional temporal dimension. This new parameter must be thought of as an implicit indexical that refers to some contextual interval of time, as in Partee's famous example:

(25) I didn't turn off the stove. (Partee 1973)

Adding this new dimension to our system follows a systematic procedure akin to the temporalization procedure of Section 4. The unary relational symbols are

systematically transformed as follows:

$$[\mathbf{professor}]_2 = \lambda xij. (j \subset i) \wedge ([\mathbf{professor}]_1 x j).$$

The binary symbols are transformed in a similar way:

$$[\mathbf{kissed}]_2 = \lambda xyij. (j \subset i) \wedge ([\mathbf{kissed}]_1 xy j).$$

As for the logical connectives and quantifiers, their new interpretation is obtained by applying twice the transformation of Section 4:

$$\begin{aligned} [\circ]_2 &= [[\circ]_1]_1, \quad \circ \in \{\wedge, \rightarrow\}, \\ [Q]_2 &= [[Q]_1]_1, \quad Q \in \{\exists, \forall\}. \end{aligned}$$

Spelling it out, it gives the following new interpretation of disjunction:

$$[\wedge]_2 = \lambda abij. (ai j) \wedge (bi j).$$

Writing prop for  $i \rightarrow i \rightarrow t$ , using boldface symbols to denote the new interpretations of the logical connectives and quantifiers, and writing  $[\_]$  for  $[\_]_2$ , the new semantic interpretation of our original grammar is still given by Table 5.

It remains to give the new interpretations of the temporal prepositions. To this end, we first adapt the definition of the temporal modalities to the two-dimensional setting:

$$\begin{aligned} \langle \mathbf{D} \rangle \phi &= \lambda ij. \exists k. (k \subset j) \wedge (\phi ik), \\ [\mathbf{D}] \phi &= \lambda ij. \forall k. (k \subset j) \rightarrow (\phi ik), \\ \langle \mathbf{B} \rangle \phi &= \lambda ij. \exists k. (k < j) \wedge (\phi ik), \\ [\mathbf{B}] \phi &= \lambda ij. \forall k. (k < j) \rightarrow (\phi ik). \end{aligned}$$

We then define an operator that allows the deictic temporal parameter to be instantiated with the current time interval:

$$\downarrow \phi = \lambda ij. \phi j j.$$

The semantic interpretation of the temporal prepositions is then defined as in Table 8.

Finally, let us check that our new two-dimensional interpretation allows one to compute the correct interpretation of sentence (24):

$$\begin{aligned} & \text{DURING}^{++}(\text{SOME}^+ \text{MONDAY})(\text{BEFORE}^{++}(\text{SOME}^+ \text{MEETING})(\text{KISSED JOHN MARY})) \\ & \rightarrow_{\beta} \exists x. ([\mathbf{monday}]x) \wedge \downarrow \langle \mathbf{D} \rangle (\exists y. ([\mathbf{meeting}]y) \wedge \langle \mathbf{B} \rangle ([\mathbf{kissed}] \mathbf{m} \mathbf{j})) \\ & \rightarrow_{\beta} \lambda ij. \exists x. (j \subset i) \wedge (\mathbf{t\_monday} x j) \wedge \\ & \quad (\downarrow (\lambda ij. \exists k. (k \subset j) \wedge (\exists y. (k \subset i) \wedge (\mathbf{t\_meeting} y k) \wedge \\ & \quad (\exists l. (l < k) \wedge (l \subset i) \wedge (\mathbf{t\_kissed} \mathbf{m} \mathbf{k} \mathbf{l})))))) i j \end{aligned}$$

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$\text{DURING}^{++} := \lambda ns. n(\lambda x. \downarrow \langle D \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{DURING}^{+-} := \lambda ns. n(\lambda x. \downarrow [D] s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{DURING}^{-+} := \lambda ns. n(\lambda x. \downarrow \langle D \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{DURING}^{--} := \lambda ns. n(\lambda x. \downarrow [D] s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{BEFORE}^{++} := \lambda ns. n(\lambda x. \langle B \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{BEFORE}^{+-} := \lambda ns. n(\lambda x. [B] s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{BEFORE}^{-+} := \lambda ns. n(\lambda x. \langle B \rangle s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$
$\text{BEFORE}^{--} := \lambda ns. n(\lambda x. [B] s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}$

**Table 8** The two-dimensional interpretation of the temporal prepositions

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$$\begin{aligned}
& \twoheadrightarrow_{\beta} \lambda ij. \exists x. (j \subset i) \wedge (\mathbf{t\_monday} x j) \wedge \\
& \quad (\exists k. (k \subset j) \wedge (\exists y. (k \subset j) \wedge (\mathbf{t\_meeting} y k) \wedge \\
& \quad (\exists l. (l < k) \wedge (l \subset j) \wedge (\mathbf{t\_kissed} m k l)))))) \\
& \equiv \lambda ij. \exists x. (j \subset i) \wedge (\mathbf{t\_monday} x j) \wedge \\
& \quad (\exists k. (k \subset j) \wedge (\exists y. (\mathbf{t\_meeting} y k) \wedge \\
& \quad (\exists l. (l < k) \wedge (l \subset j) \wedge (\mathbf{t\_kissed} m k l))))).
\end{aligned}$$

## 7 Pratt and Francez's solution revisited

The polarized system we have developed in the two preceding sections could be adapted in order to cope with generalized quantifiers that are monotone (upward or downward) in their first argument. We do not know, however, how to adapt it in order to handle generalized quantifiers that do not satisfy this monotonicity property (such as *most*, for instance). This is a drawback with respect to Pratt and Francez's system. In order to circumvent it, let us try to recast Pratt and Francez's analysis in our setting.

Using our notations, the semantic interpretation that Pratt & Francez 2001 assign to the noun *meeting* is the following:

$$(26) \quad \text{MEETING} := \lambda xi. (\mathbf{meeting} x) \wedge ((\tau x) \subset i).$$

Then, in order to avoid the use of the operator  $\tau$ , (26) may be rewritten as (27), or equivalently as (28):

$$(27) \quad \text{MEETING} := \lambda xi. \exists j. (\mathbf{t\_meeting} x j) \wedge (j \subset i),$$

$$(28) \quad \text{MEETING} := \lambda x. \langle D \rangle ([\mathbf{meeting}]_1 x).$$

Now, the problem with a universally quantified prepositional phrase such as *during every meeting* is that the existential quantifier occurring in (27) must be

turned into a universal quantifier that takes scope over the complete sentence. This is, in fact, reminiscent of donkey sentences. For this reason, we will apply to our original grammar a continuation-based transformation inspired by the dynamic logic developed in [de Groot 2006](#) and [Lebedeva 2012](#).<sup>9</sup>

Roughly speaking, this transformation adds a conjunctive continuation to each atomic formula. In the case of a standard unary predicate symbol, it is indeed defined as follows:

$$[\mathbf{professor}]_3 = \lambda xc. ([\mathbf{professor}]_1 x) [\wedge]_1 c.$$

In the case of a unary predicate symbol whose argument is an event-like entity (or in the case of a predicate corresponding to a non-transitive verb), the transformation is defined in such a way that it reflects an interpretation akin to (28):

$$[\mathbf{meeting}]_3 = \lambda xc. \langle D \rangle (([\mathbf{meeting}]_1 x) [\wedge]_1 c).$$

In the case of a binary predicate symbol corresponding to a transitive verb, the transformation is defined in a similar way:

$$[\mathbf{kissed}]_3 = \lambda xyc. \langle D \rangle (([\mathbf{kissed}]_1 xy) [\wedge]_1 c).$$

Let  $\text{STOP} = \lambda i. \mathbf{true}$  be the empty continuation. Negation, conjunction, and existential quantification are defined as follows:

$$\begin{aligned} [\neg]_3 &= \lambda ac. ([\neg]_1 (a \text{STOP})) [\wedge]_1 c, \\ [\wedge]_3 &= \lambda abc. a (bc), \\ [\exists]_3 &= \lambda pc. [\exists]_1 (\lambda x. pxc). \end{aligned}$$

Finally, implication and universal quantification are defined using de Morgan's laws:

$$\begin{aligned} [\rightarrow]_3 &= \lambda ab. [\neg]_3 (a [\wedge]_3 ([\neg]_3 b)), \\ [\forall]_3 &= \lambda p. [\neg]_3 ([\exists]_3 (\lambda x. [\neg]_3 (px))). \end{aligned}$$

In this new setting, the type of the propositions is the following:

$$\text{prop} = (i \rightarrow t) \rightarrow (i \rightarrow t).$$

Then, *mutatis mutandis*, the new semantic interpretation of our original grammar is still given by Table 5.

It remains to give the new semantic interpretation of *during*. It is simply defined as follows:

<sup>9</sup> As a matter of fact, the transformation we are using corresponds exactly to the *dynamicization* transformation of [Kobele 2015](#).

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$$(29) \quad \text{DURING} := \lambda ns.n(\lambda x.s) : e^* \rightarrow \text{prop} \rightarrow \text{prop}.$$

We may now check that this new system makes the right prediction for sentence (1):

$$\begin{aligned} & \text{DURING}(\text{SOME MONDAY})(\text{DURING}(\text{EVERY MEETING})(\text{KISSED JOHN MARY})) \\ & \rightarrow_{\beta} \exists x. ([\mathbf{monday}]x) \wedge (\forall y. ([\mathbf{meeting}]y) \rightarrow ([\mathbf{kissed}] \mathbf{m} \mathbf{j})) \\ & \rightarrow_{\beta} \lambda c. [\exists]_1 x. \langle D \rangle (([\mathbf{monday}]_1 x) \\ & \quad [\wedge]_1 ([\forall]_1 y. [D] (([\mathbf{meeting}]_1 y) [\rightarrow]_1 \langle D \rangle ([\mathbf{kissed}]_1 \mathbf{m} \mathbf{j})))) \\ & \quad [\wedge]_1 c) \\ & \rightarrow_{\beta} \lambda ci. \exists xj. (j \subset i) \\ & \quad \wedge (\mathbf{t\_monday} x j) \\ & \quad \wedge (\forall yk. (k \subset j) \rightarrow ((\mathbf{t\_meeting} y k) \\ & \quad \rightarrow ((\exists l. (l \subset k) \wedge (\mathbf{t\_kissed} \mathbf{m} \mathbf{j} l)))))) \\ & \quad \wedge (c j). \end{aligned}$$

## 8 Putting everything together

Up to now, we have developed two different systems: a polarity-based system (Section 5 and 6), and a continuation-based system (Section 7). On the one hand, the polarity-based system offers a uniform treatment of the temporal propositions. Unfortunately, it seems that the polarity calculus on which this system is based does not permit a treatment of all the generalized quantifiers. On the other hand, the continuation-based system, which is derived from Pratt and Francez's solution, could cope with all the generalized quantifiers, but does not permit a uniform treatment of the temporal propositions. In this section, we will merge our two systems in order to combine their respective advantages.

Consider the semantic interpretation that the continuation-based system assigns to the noun *meeting*:

$$(30) \quad [\mathbf{meeting}]_3 = \lambda xc. \langle D \rangle (([\mathbf{meeting}]_1 x) [\wedge]_1 c).$$

This interpretation (as well as the interpretations of other lexical items such as verbs) contains the during-modality. For this reason, as in Pratt and Francez's system, the interpretation of the preposition *during* is rather opaque. In fact, it is a pure combinator – see (29). A possible way out of this problem is to replace the modality occurring in (30) by a parameter. This would give rise to the following interpretation (in the case of a two-dimensional system):

$$(31) \quad \lambda xfc.f(([\mathbf{meeting}]_2 x) [\wedge]_2 c).$$

In order to exploit this idea, let us work out the type of expression (31). Let



$T = i \rightarrow i \rightarrow t$  be the type of a two-dimensional temporal proposition. We have that  $([\mathbf{meeting}]_2 x) [\wedge]_2 c$  is of type  $T$ , and so is  $c$ . Consequently,  $f$  must be of type  $(T \rightarrow T)$ , and the complete expression is of type  $e \rightarrow (T \rightarrow T) \rightarrow T \rightarrow T$ . This leads us to define the type of the propositions as follows:

$$\text{prop} = (T \rightarrow T) \rightarrow T \rightarrow T.$$

Now, in order to define a logic acting on propositions of the above type, the first step is to adapt the dynamic logic of Section 7 to the two-dimensional framework. Let  $\text{STOP} = \lambda i j. \mathbf{true}$  be the two-dimensional empty continuation. The two-dimensional dynamic logic operators are defined as follows:

$$\begin{aligned} [\neg]_4 &= \lambda a c. ([\neg]_2 (a \text{STOP})) [\wedge]_2 c, \\ [\wedge]_4 &= \lambda a b c. a (b c), \\ [\exists]_4 &= \lambda p c. [\exists]_2 (\lambda x. p x c). \end{aligned}$$

We are now in a position of defining our ultimate transformation. The transformation of a predicate symbol whose argument is an event-like entity conforms with expression (31), and so is the transformation of a predicate symbol corresponding to a verb:

$$\begin{aligned} [\mathbf{meeting}]_5 &= \lambda x f c. f (([\mathbf{meeting}]_2 x) [\wedge]_2 c), \\ [\mathbf{kissed}]_5 &= \lambda x y f c. f (([\mathbf{kissed}]_2 x y) [\wedge]_2 c). \end{aligned}$$

Concerning the predicate symbols whose argument is not an event-like entity, their transformation is as follows:

$$[\mathbf{professor}]_5 = \lambda x f c. ([\mathbf{professor}]_2 x) [\wedge]_2 c.$$

Finally, let  $\text{ID} = \lambda x. x$  be the identity. The transformation of the logical connectives and quantifiers is defined as follows:

$$\begin{aligned} [\neg]_5 &= \lambda a f. [\neg]_4 (a f), \\ [\wedge]_5 &= \lambda a b f. (a f) [\wedge]_4 (b \text{ID}), \\ [\exists]_5 &= \lambda p f. [\exists]_4 (\lambda x. p x f), \\ [\rightarrow]_5 &= \lambda a b. [\neg]_5 (a [\wedge]_5 ([\neg]_5 b)), \\ [\forall]_5 &= \lambda p. [\neg]_5 ([\exists]_5 (\lambda x. [\neg]_5 (p x))). \end{aligned}$$

Using our usual notational conventions (i.e., writing  $[\_]$  for  $[\_]_5$ , and using boldface symbols to denote the new interpretation of the logical symbols), the ultimate interpretation of our original grammar is still given by Table 5. Moreover, it would not be too difficult to establish, for this ultimate interpretation, a conservativity property similar to the one we have sketched in Section 4.

We may now give the new interpretation of the temporal prepositions, which will be responsible for instantiating the parameter  $f$  with the appropriate modality. Their definitions are as follows:

$$\begin{aligned} \text{DURING} &:= \lambda ns.n(\lambda xf.s(\lambda a.\downarrow\langle D \rangle a)) : e^* \rightarrow \text{prop} \rightarrow \text{prop}, \\ \text{BEFORE} &:= \lambda ns.n(\lambda xf.s(\lambda a.\langle B \rangle a)) : e^* \rightarrow \text{prop} \rightarrow \text{prop}. \end{aligned}$$

To conclude, let us see how this last system works in the case of sentence (24). Let us first compute the interpretation of *Mary kissed John before some meeting*:

$$\begin{aligned} &\text{BEFORE (SOME MEETING) (KISSED JOHN MARY)} \\ &\rightarrow_{\beta} \exists y. ([\text{meeting}]_y) \wedge (\lambda f. [\text{kissed}] \mathbf{m} \mathbf{j} (\lambda a. \langle B \rangle a)) \\ &\rightarrow_{\beta} \exists y. ([\text{meeting}]_y) \wedge (\lambda f. (\lambda fc. f([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c)) (\lambda a. \langle B \rangle a) \\ &\rightarrow_{\beta} \exists y. ([\text{meeting}]_y) \wedge (\lambda fc. \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c) \\ &\rightarrow_{\beta} \exists y. \lambda f. ([\text{meeting}]_y f) [\wedge]_4 ((\lambda fc. \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c)) \text{ID} \\ &\rightarrow_{\beta} \exists y. \lambda f. (\lambda c. f([\text{meeting}]_2 y) [\wedge]_2 c) [\wedge]_4 (\lambda c. \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c) \\ &\rightarrow_{\beta} \exists y. \lambda fc. f([\text{meeting}]_2 y) [\wedge]_2 \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c) \\ &\rightarrow_{\beta} \lambda f. [\exists]_4 y. \lambda c. f([\text{meeting}]_2 y) [\wedge]_2 \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c) \\ &\rightarrow_{\beta} \lambda fc. [\exists]_2 y. f([\text{meeting}]_2 y) [\wedge]_2 \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}) [\wedge]_2 c). \end{aligned}$$

Let us call the above  $\lambda$ -term  $S_0$ . The expression corresponding to sentence (24) may be reduced in a similar way:

$$\begin{aligned} &\text{DURING (SOME MONDAY) (BEFORE (SOME MEETING) (KISSED JOHN MARY))} \\ &\rightarrow_{\beta} \lambda fc. [\exists]_2 x. f([\text{monday}]_2 x) [\wedge]_2 \downarrow \langle D \rangle (S_0 \text{ID } c). \end{aligned}$$

Let us call this second  $\lambda$ -term  $S_1$ . In order to obtain a final reading, we may apply it to the identity and to the empty continuation:

$$\begin{aligned} &S_1 \text{ID STOP} \\ &\rightarrow_{\beta} [\exists]_2 x. \text{ID} ([\text{monday}]_2 x) [\wedge]_2 \downarrow \langle D \rangle (S_0 \text{ID STOP}) \\ &\rightarrow_{\beta} [\exists]_2 x. [\text{monday}]_2 x [\wedge]_2 \downarrow \langle D \rangle ([\exists]_2 y. ([\text{meeting}]_2 y) [\wedge]_2 \langle B \rangle ([\text{kissed}]_2 \mathbf{m} \mathbf{j}))). \end{aligned}$$

Then, the reduction continues as in the two-dimensional system of Section 6.

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