Event Quantification in Infinitival Complements: A Free-Logic Approach

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Abstract. In this paper, I argue that some infinitival complements can be analyzed as an argument of verbs, in the same way of perception verb analysis (Higginbotham 1983). Then, I consider an event quantification problem in infinitival complements, showing that quantificational event semantics (Champollion 2015) and free logic are the keys to solving it.

Keywords: Event semantics · Event quantification problem

1 Introduction

Some previous papers in (neo-) Davidsonian semantics (Higginbotham 1983; Parsons 1991) propose that an infinitival complement serves as an argument to perception verbs. I generalize this approach to some other infinitival complements. However, these previous studies do not consider the event quantification problem in infinitival complements. Champollion (2015) proposed that a sentence has a GQ type over events. In an opaque context, however, if an infinitival complement is regarded as a GQ-type argument, entailment relations wreak havoc, since all verbs contain an existential quantifier binding an event variable.

I will support Champollion's framework, admitting eventualities which do not exist and assuming that "existence of an eventuality" in some sense corresponds to a predicate or a property for an eventuality. This idea is adequately formalized by using free logic.

1.1 Entailment Relations in Event Semantics

In neo-Davidsonian semantics (Parsons 1990), the logical form of a sentence contains an event variable and an existential quantifier $\exists$ binding the variable (*event quantifier*). One of the virtues of the neo-Davidsonian framework is that this can adequately explain deductive relations among some sentences.

K. Kojima et al. (Eds.): JSAI-isAI 2018 Workshops, LNAI 11717, pp. 372–384, 2019.
https://doi.org/10.1007/978-3-030-31605-1_27

(1) a. Brutus stabbed Caesar violently yesterday.
   b. Brutus stabbed Caesar violently.
   c. Brutus stabbed Caesar yesterday.
   d. Brutus stabbed Caesar.

(1a) entails both (1b) and (1c), and (1d) is entailed by all of them. Neo-Davidsonian logical form can capture these entailment relations by ordinary predicate logic. Here I use thematic role functions **ag** and **th** which take an event argument.

(2) a. $\exists e.\mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = \mathbf{b} \wedge \mathbf{violent}(e) \wedge \mathbf{yesterday}(e)$
   b. $\exists e.\mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = \mathbf{b} \wedge \mathbf{violent}(e)$
   c. $\exists e.\mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = \mathbf{b} \wedge \mathbf{yesterday}(e)$
   d. $\exists e.\mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = \mathbf{b}$

It is apparent that (2a) entails (2b) and (2c), and so is that all of them entail (2d).

1.2 Scope Domain Principle

There are already ample debates on quantification in (neo-) Davidsonian event semantics. For example, take the sentence *Nobody stabbed Caesar*. This is not ambiguous with respect to scope order of *Nobody* binding z and the existential quantifier binding e.

(3) Nobody stabbed Caesar.
   a. $\neg\exists z.[\mathbf{person}(z) \wedge \exists e.[\mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = z]]$
   (correct)
   b. $\exists e.[\neg\exists z.[\mathbf{person}(z) \wedge \mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = z]]$
   (incorrect)

In (3a), an existential quantifier which binds an event variable e takes scope under the quantificational argument *nobody*, whereas (3b) has an existential quantifier which takes the highest scope. (3a) is correctly inconsistent with (2d), just like our intuition for (3). However, (3b) is wrongly consistent with (2d), in that (3b) merely commits to the existence of some irrelevant event e, which is not a one of stabbing of Caesar by someone ($\exists z.[\mathbf{person}(z) \wedge \mathbf{stabbing}(e) \wedge \mathbf{th}(e) = \mathbf{c} \wedge \mathbf{ag}(e) = z]$). Thus, (3b) is an incorrect description of the meaning of (3). However, most of the neo-Davidsonian framework assumes that the event variable is bound at sentence level, and quantificational NPs occur under the event quantifier.

The first solution to this problem of quantifier scope is the mereological one, as proposed by Krifka (1989). He used subevents which the event argument in the clause consists of. This theory can explain the meaning of sentences like *three* *girls ate seven apples*. However, some papers (Champollion 2015, among others) pointed out that a mereological solution occasionally faces difficulties. I will not dwell on this theory here.

Landman (1996) suggested that the existential quantifier which binds an event argument obligatorily takes the lowest scope. Landman (1996, 2000) calls that constraint the *scope domain principle* as defined below:

(4) Scope domain principle: Non-quantificational NPs can be entered into scope domains. Quantificational NPs cannot be entered into scope domains.

This constraint says, in other words, that all quantificational noun phrases such as *nobody* must take scope over and cannot take scope under the existential quantifier for the event argument in a clause.

There are already discussions on the solution to the *Event Quantification Problem (EQP)*, which forces quantificational noun phrases to take scope over event quantifiers (Champollion 2015; de Groote and Winter 2015; Luo and Soloviev 2017; Winter and Zwarts 2011)[1]. However, as far as I am aware, no one considers quantification in (infinitival) complements.

2 Problems: Nonexistent Events and Event Quantification

I here consider a semantics of infinitival complements.

One of the most popular semantic approaches to complement clauses assumes that a clause denotes a set of possible worlds. For example, an infinitival clause *2 (to) be a prime number* can be analyzed as the following formula.

(5)

This approach has some counterexamples, such as, a pair of sentences *Mary considered 2 to be a prime number* and *Mary considered 5 to be a prime number*. Although these two sentences have different infinitival complements respectively, their meaning is not distinguishable in the possible world framework.

(6) a. $[\![\text{2 to be a prime number}]\!] \rightsquigarrow \{w \mid 2 \text{ is a prime number in } w\}$

b. $[\![\text{5 to be a prime number}]\!] \rightsquigarrow \{w \mid 5 \text{ is a prime number in } w\}$

[1] Luo and Soloviev (2017) argues that Dependent Type Semantics (DTS) can provide an account for the EQP. They addressed a question about *why does the event quantifier take scope under all of the others* from a semantic point of view. In contrast, other studies (Champollion 2015; de Groote and Winter 2015; Winter and Zwarts 2011) proposed a solution for a problem about *how does the event quantifier take scope under all of the others*. In other words, strictly speaking, Luo and Soloviev (2017) considered a different question.

Since 2 and 5 are rigid designators and are prime in all possible worlds, (6a) and (6b) denote the same sets of possible worlds. Thus we cannot tell the semantic difference between (6a) and (6b). In contrast, Higginbotham (1983) and Parsons (1991) argued that perception verbs take an event argument of subordinate complements as their internal argument. In Higginbotham (1983), the (naked) infinitival complement covertly moves to the matrix position. Then, the trace in the complement position of perception verbs is interpreted as an event variable, being bound by the event quantifier in the moved complement. Parsons (1991) proposed that a sentence denotes an eventuality, and the truth condition of the sentence ϕ is given by $\mathbf{E!}(\phi)$. $\mathbf{E!}(t)$ is true iff t exists, iff t belongs to the class of existent entities. This means that a sentential denotation can become an event which does not exist.

2.1 First Tentative Approach: Parsons (1991)

Following Parsons (1991), I tentatively assume that sentences are symbolized as definite descriptions of eventualities, which have a type v. Then, the complements are distinguishable semantically.

(7) a. $\iota e.[\mathbf{prime}(e) \wedge \mathbf{th}(e) = 2]$

b. $\iota e.[\mathbf{prime}(e) \wedge \mathbf{th}(e) = 5]$

(7a) and (7b) denote an event of 2 being a prime number and an event of 5 being a prime number, respectively. They are distinguishable since $\mathbf{th}(e)$ has different values. Although this approach successfully solves the problem, Parsons (1991) does not consider the event quantification problem. Since he assume that a sentence denotes an eventuality, if an iota operator for an event variable is given to this infinitival complement, quantificational NPs such as *no student* cannot take scope over event arguments. For instance, although *no student left* means there is no event of leaving by students, this approach cannot give a correct denotation for this sentence.

2.2 Second Tentative Approach: Champollion (2015)

Champollion (2015) proposed an elegant framework which obeys (4). He assumes that all verbs contain an existential quantifier which binds an event variable.

(8) a. $[\![\text{leave}]\!] \rightsquigarrow \lambda f.\exists e.[\mathbf{leaving}(e) \wedge f(e)]$

b. $[\![\text{forbid}]\!] \rightsquigarrow \lambda f.\exists e.[\mathbf{forbidding}(e) \wedge f(e)]$

He also considers that thematic predicates are lexically separated ($[\mathbf{r}]$, where $\mathbf{r}$ is a thematic function, e.g., $\mathbf{ag}, \mathbf{th}, \mathbf{ex}, \ldots$), assuming all NPs have a GQ type (over entities).

(9) $[\![\text{NP} + [\mathbf{r}]]\!] \rightsquigarrow \lambda N \lambda f.[[\![\text{NP}]\!](\lambda x.[N(\lambda e.\mathbf{r}(e) = x \wedge f(e)])])]$

The sentence denotes a GQ-type expression over events. Following Champollion (2015) straightforwardly, I assume that infinitival complements are treated as GQ arguments. Then they are analyzed just like NPs.

(10) $[\![\text{every student (to) leave}]\!]$
$\rightsquigarrow \lambda f.\forall x.[\mathbf{student}(x) \rightarrow \exists e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge f(e')]]$

(10) has a GQ type over events ($\langle vt, t\rangle$). Thus (10) can be treated as a GQ argument of the verb. Now, with the sentential closure $\lambda e.\top$, the perceptual verb construction is analyzed as follows.

(11) $[\![\text{Mary saw every student leave}]\!](\lambda e.\top)$
$\rightsquigarrow \forall x.[\mathbf{student}(x) \rightarrow \exists e'.[\exists e.[\mathbf{seeing}(e) \wedge \mathbf{leaving}(e')$
$\wedge\ \mathbf{ag}(e') = x \wedge \mathbf{th}(e) = e' \wedge \mathbf{ag}(e) = \mathbf{m}]]]$

(11) satisfies the scope domain principle (4). One of the challenges for this approach is the factivity of embedded infinitives in opaque contexts. For instance, verbs which take an infinitive entail different consequences.

(12) a. Mary saw every student leave $\Rightarrow$ Every student left.

b. Mary forbade every student to leave. $\not\Rightarrow$ Every student left.

Interpretation of infinitival complements as GQ arguments is inconsistent with the entailment relations in (12b) because the Champollionian denotation for the infinitival complement *every student to leave* contains the existential quantifier which binds an event variable.

(13) $[\![(12\text{b})]\!](\lambda e.\top)$
$\rightsquigarrow \forall x.[\mathbf{student}(x) \rightarrow \exists e'.[\exists e.[\mathbf{forbidding}(e) \wedge \mathbf{leaving}(e')$
$\wedge\ \mathbf{ag}(e') = x \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m}]]]$

In (13), since the event variable for *leaving* is bound by the existential quantifier, this event must take place. I will modify Champollion's framework in a later section.

3 Free Logic

Free logic is an extension of the first-order system. In free logic, the quantificational domain contains entities which do not exist. Then, both universal and existential quantifiers are split into outer and inner quantifiers.

(14) Existential quantifiers

a. Σ: outer existential quantifier

b. $\exists$: inner existential quantifier

(15) Universal quantifiers

a. Π: outer universal quantifier

b. ∀: inner universal quantifier

These inner quantifiers are different from outer quantifiers in that the domain of quantification is restricted to a class of existing entities. Inner quantifiers can be defined in terms of the outer quantifiers and the existence predicate **E!**.

(16) a. $\exists x.\phi(x) := \Sigma x.\mathbf{E!}(x) \wedge \phi(x)$

b. $\forall x.\phi(x) := \Pi x.\mathbf{E!}(x) \rightarrow \phi(x)$

I argue that Parsons (1991) is compatible with quantificational event semantics if all verbs contain the outer existential quantifier instead of the inner one. Following this assumption, I support a quantificational event semantics with indirect evidence. I admit an eventuality which does not exist at the world and assume that "existence of an eventuality at the world" in some sense corresponds to a predicate or a property for an eventuality. I assume positive semantics, which allows some propositions of the form $P(a)$ to be true even if a does not exist. This idea is adequately formalized by using free logic. Although accepting nonexistent entities is severely criticized by Russell (1905) and Quine (1948), Parsons (1991) and I use the existence predicate for eventuality terms only. Thus, this assumption is outside the scope of their criticism.

4 Outer-Quantificational Event Semantics

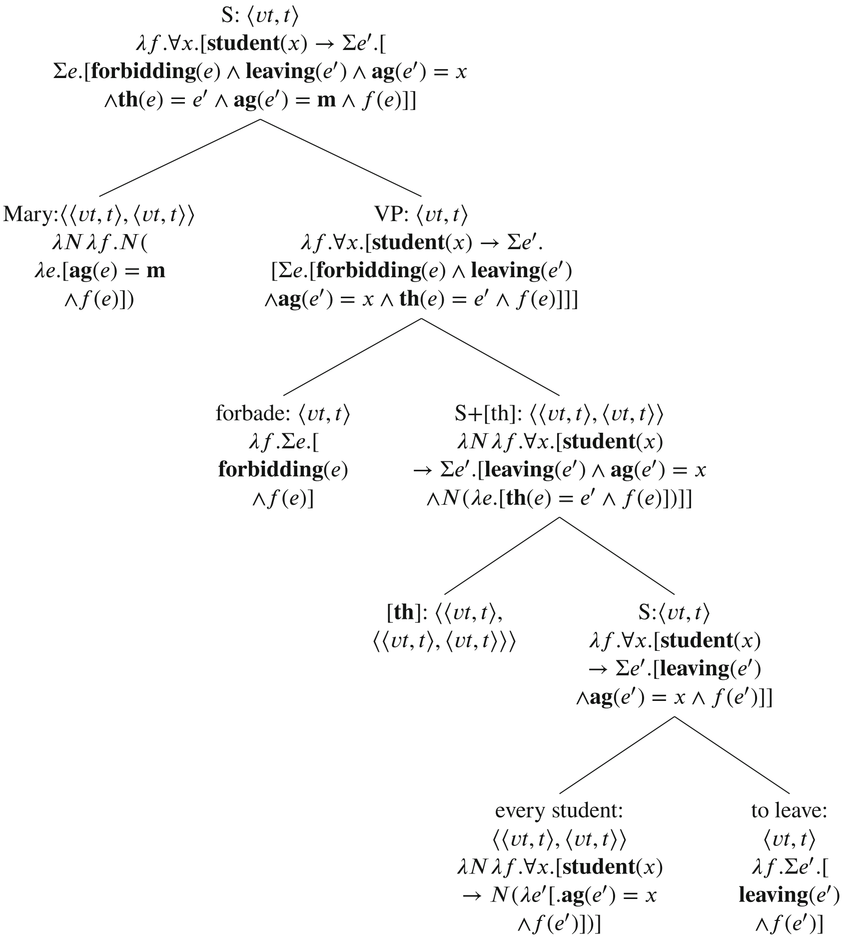
I now modify quantificational event semantics using the outer existential quantifier and the existence predicate, generalizing approaches for perceptual reports (Higginbotham 1983; Parsons 1991) to other verbs which take an infinitival complement. A verbal denotation's existential quantifier is replaced with the outer one.

(17) a. $[\![\text{(to) leave}]\!] \rightsquigarrow \lambda f.\Sigma e.[\mathbf{leaving}(e) \wedge f(e)]$

b. $[\![\text{forbid}]\!] \rightsquigarrow \lambda f.\Sigma e.[\mathbf{forbidding}(e) \wedge f(e)]$

Now the meaning of (12b) is composed in the following way.

(18) $\lambda f.\forall x.[\mathbf{student}(x) \rightarrow \Sigma e'.[\Sigma e.[\mathbf{forbidding}(e) \wedge \mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \mathbf{cont}(e) = e' \wedge \mathbf{ag}(e) = \mathbf{m} \wedge f(e)]]]$



Instead of $\lambda e.\top$, the original sentential closure in Champollion (2015), I adopt **E!** as such closure.

(19) (18) (**E!**) $\rightsquigarrow \forall x.[\mathbf{student}(x) \rightarrow \Sigma e'.[\exists e.[\mathbf{forbidding}(e) \wedge \mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \mathbf{th}(e) = e' \wedge \mathbf{ag}(e) = \mathbf{m}]]]$

The truth condition of (18) is given by (19). Note that **E!** is applied to e but not to e', since the embedded infinitival clause is treated as an argument of the matrix verb. This does not entail, but is compatible with a situation in which *every student left* because (19) implies $\forall x.[\mathbf{student}(x) \rightarrow \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x]]$, which does not commit to the existence of any leaving eventuality. Now, although the denotation for (12a) does not entail *every student left*, I argue that complements of perceptual verbs denote (20).

Table 1. Variants of neo-Davidsonian frameworks

	Sentential denotation type	Semantic closure	Scope domain principle	Nonexistent event
Landman (2000)	vt	$\lambda P.\exists e.P(e)$	✓	×
Parsons (1991)	v	$\mathbf{E!}$	×	✓
Winter and Zwarts (2011)	$\langle\langle vt, t\rangle, t\rangle$	$\lambda P.\exists e.P(e)$	✓	×
Champollion (2015)	$\langle vt, t\rangle$	$\lambda e.\top$	✓	×
My proposal	$\langle vt, t\rangle$	$\mathbf{E!}$	✓	✓

(20) $[\![\text{XP} + [\mathbf{th}]]\!] \rightsquigarrow \lambda N \lambda f.[[\![\text{XP}]\!](\lambda x.[N(\lambda e.\mathbf{th}(e) = x \wedge \mathbf{E!}(x) \wedge f(e))])]$

Then (12a) entails *every student left* since **E!** applies to the embedded event.

Figure 1 shows the summary of neo-Davidsonian variants. This paper is considering both the event quantification problem and entailment relations with nonexistent events.

4.1 Limitations

This paper does not treat entailment of non-existence. For example, *Negotiation prevented a strike* entails there exists no eventuality of a strike (Condoravdi et al. 2001).

This paper (and Parsons's approach) cannot address the problem such as:

(21) a. Ralph considers the man in the brown hat to be a spy

b. Ralph considers the man seen at the beach not to be a spy

In both sentences, *the man* denotes the same entity in context. However, both sentences can have different values (Quine 1956).

5 Concluding Remarks

Free logic can give a generalized treatment of infinitival complements in neo-Davidsonian semantics. As assumed in Champollion (2015), verbs contain an existential quantifier, but I argue that the domain of the quantifier contains nonexistent events. The proposed framework avoids the problem on scope domain principle and entailment relations with nonexistent events. If this approach is correct, it becomes plausible that infinitival complements are semantically regarded as an argument of attitude verbs, just like in the cases of a perception verb.

Acknowledgement. I am very grateful to Hitomi Hirayama, Makoto Kanazawa, and Chris Tancredi for their insightful discussion. I also thank two anonymous reviewers for their helpful comments. Needless to say, all remaining errors are my own.

A Appendix: Formal Syntax for the Quantificational Event Semantics

In this appendix, I offer a simple grammar formalism which the quantificational event semantics is based on.

A.1 Directional Minimalist Grammar without MOVE

I introduce a (tiny) variant of *Directional Minimalist Grammars* (DMGs, Stabler 2011). Though the original DMGs have a MOVE operation, here I present a grammar formalism without MOVE to avoid unnecessary complexities. Similar approaches are adopted by Hunter (2010) and Tomita (2016).

Notations. Here I lay out formal notations which I use in this appendix.

A finite set of *phonological expressions* (or *strings*) V contains items such as `Mary`, `forbade`, `(to) leave`, ..., and the empty string ε. A set of *category features* B contains items such as `c`, `d`, `v`, ... This set determines a set of (right and left) selector features $B_{=} = \{\texttt{b=} \mid \texttt{b} \in B\} \cup \{\texttt{=b} \mid \texttt{b} \in B\}$. Both category and selector features are called *syntacitic features*. A set of sequences of syntacitic features *Syn* is defined as $B_{=}^{*} \times B$.

$$\frac{s : \texttt{b=}, \phi \qquad t : \texttt{b}}{st : \phi}\ \text{MRG}_1 \qquad\qquad \frac{t : \texttt{b} \qquad s : \texttt{=b}, \phi}{ts : \phi}\ \text{MRG}_2 \qquad (s, t \in V^{*}, \texttt{b} \in B, \phi \in Syn)$$

Fig. 1. Operation for DMGs

Grammar. The grammar formalism consists of a set of category features B, a set of phonological expressions V, and a finite set *Lex*, which consists of tuples of a phonological expression and a sequence of syntactic features, i.e., $Lex \subseteq V \times Syn$.

The grammar has a structure-building function called MERGE, which takes two expressions and combines them, concatenating two strings and saturating the leftmost selector feature with a corresponding category feature. This function is a union of two sub-operations, MRG_1 and MRG_2 shown in Fig. 1.

The set of well-formed expressions is a closure of expressions in *Lex* under MERGE. A derivation is completed when the only remaining feature in the well-formed expression is `c`.

A.2 Combination of the Grammar Formalism and Quantificational Event Semantics

On the semantic side of things, a minimalist expression is a sequence of pairs of both a syntactic feature and a semantic component. Following Hunter (2010) and Tomita (2016), I assume that the meaning of each verb consists of multiple semantic components.

First, verbal denotations are assigned to each category feature `v` in verbs.

(22) Verbal denotation:

$$\mathcal{P}_{\mathbf{V}} := \lambda f.\Sigma e.\mathbf{V}(e) \wedge f(e)$$

where **V** is a verbal predicate constant (e.g. **stabbing**, **finding**,...) of type vt.

Second, a thematic predicate is assigned to each selector feature, being separated from the verbal denotation.

Table 2. A fragment for the free-logic approach

nominal elements	`Mary`	: $\langle \mathtt{d}, \lambda k.k(\mathbf{m})\rangle$
	`someone`	: $\langle \mathtt{d}, \lambda k.\exists x.[\mathbf{person}(x) \wedge k(x)]\rangle$
	`everyone`	: $\langle \mathtt{d}, \lambda k.\forall x.[\mathbf{person}(x) \rightarrow k(x)]\rangle$
verbal elements	`(to) leave`	: $\langle \mathtt{=d}, \theta_{\mathbf{ag}}\rangle\langle \mathtt{v}, \mathcal{P}_{\mathbf{leaving}}\rangle$
	`forbade`	: $\langle \mathtt{v=}, \theta_{\mathbf{th}}\rangle\langle \mathtt{=d}, \theta_{\mathbf{ag}}\rangle\langle \mathtt{v}, \mathcal{P}_{\mathbf{forbidding}}\rangle$
	`saw`	: $\langle \mathtt{v=}, \theta^{\mathbf{E!}}_{\mathbf{th}}\rangle\langle \mathtt{=d}, \theta_{\mathbf{ex}}\rangle\langle \mathtt{v}, \mathcal{P}_{\mathbf{seeing}}\rangle$
functional elements	ε	: $\langle \mathtt{v=}, I\rangle\langle \mathtt{c}, \mathbf{E!}\rangle$

(23) Thematic predicates:

$$\theta_{\mathbf{r}} := \lambda MNf.[M(\lambda x.[N(\lambda e.[\mathbf{r}(e) = x \wedge f(e)])])]$$

where **r** is a thematic role function of type ve such as **ag**, **th**,.... The leftmost selector feature in perceptual verbs is anntated with the different thematic predicate which contains the existence predicate.

(24) Thematic predicates for perceptual verbs:

$$\theta^{\mathbf{E!}}_{\mathbf{th}} := \lambda MNf.[M(\lambda x.[N(\lambda e.[\mathbf{th}(e) = x \wedge \mathbf{E!}(x) \wedge f(e)])])]$$

A fragment of the grammar formalism with semantics is shown in Table 2.

Composition Scheme. The meaning of complex expressions (sentences and phrases) is composed via MERGE in derivations.

A composition scheme for MERGE is as follows. Along the lines of Tomita (2016), MERGE involves the functional application of an argument Q and a semantic component R assigned to the leftmost selector `b=` or `=b`. Then, this semantic component is applied to P, being assigned to the remaining category feature `b`'.

(25) Compositional scheme for MRG_1:

$$\frac{s : \langle \texttt{b=}, R\rangle\langle \texttt{f}_1, R_1\rangle \ldots \langle \texttt{f}_n, R_n\rangle\langle \texttt{b}', P\rangle \qquad t : \langle \texttt{b}, Q\rangle}{st : \langle \texttt{f}_1, R_1\rangle \ldots \langle \texttt{f}_n, R_n\rangle\langle \texttt{b}', R(Q)(P)\rangle}\ \mathrm{MRG}_1$$

(26) Compositional scheme for MRG_2:

$$\frac{t : \langle \texttt{b}, Q\rangle \qquad s : \langle \texttt{=b}, R\rangle\langle \texttt{f}_1, R_1\rangle \ldots \langle \texttt{f}_n, R_n\rangle\langle \texttt{b}', P\rangle}{ts : \langle \texttt{f}_1, R_1\rangle \ldots \langle \texttt{f}_n, R_n\rangle\langle \texttt{b}', R(Q)(P)\rangle}\ \mathrm{MRG}_2$$

where P, Q, R, R_i are semantic components, s and t range over sequences of strings in V^*, $\texttt{b}$ and $\texttt{b}'$ range over category features in B, and $\texttt{f}_i$ ranges over selector features in $B_{\texttt{=}}$ for $1 \leq i \leq n$. Example derivations for *Mary saw everyone leave* and *Mary forbade everyone to leave* are shown in Figs. 2 and 3, respectively.

$$(26)\ \frac{\texttt{everyone}:\ \langle \texttt{d}, \lambda k.\forall x.[\mathbf{person}(x) \to k(x)]\rangle \qquad \texttt{leave}:\ \langle \texttt{=d}, \theta_{\mathbf{ag}}\rangle\langle \texttt{v}, \mathcal{P}_{\mathbf{beating}}\rangle}{\texttt{everyone leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge f(e')]]\rangle}\ \mathrm{MRG}_2$$

$$(25)\ \frac{\texttt{saw}:\ \langle \texttt{v=}, \theta^{\mathbf{E!}}_{\mathbf{th}}\rangle\langle \texttt{=d}, \theta_{\mathbf{ex}}\rangle\langle \texttt{v}, \mathcal{P}_{\mathbf{seeing}}\rangle \qquad \texttt{everyone leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge f(e')]]\rangle}{\texttt{saw everyone leave}:\ \langle \texttt{=d}, \theta_{\mathbf{ex}}\rangle\langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \exists e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{seeing}(e) \wedge \mathbf{th}(e) = e' \wedge f(e)]]]\rangle}\ \mathrm{MRG}_1$$

$$(26)\ \frac{\texttt{Mary}:\ \langle \texttt{d}, \lambda k.k(\mathbf{m})\rangle \qquad \texttt{saw everyone leave}:\ \langle \texttt{=d}, \theta_{\mathbf{ex}}\rangle\langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \exists e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{seeing}(e) \wedge \mathbf{th}(e) = e' \wedge f(e)]]]\rangle}{\texttt{Mary saw everyone leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \exists e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{seeing}(e) \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m} \wedge f(e)]]]]\rangle}\ \mathrm{MRG}_2$$

$$(25)\ \frac{\varepsilon:\ \langle \texttt{v=}, I\rangle\langle \texttt{c}, \mathbf{E!}\rangle \qquad \texttt{Mary saw everyone leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \exists e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{seeing}(e) \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m} \wedge f(e)]]]]\rangle}{\texttt{Mary saw everyone leave}:\ \langle \texttt{v}, \forall x.[\mathbf{person}(x) \to \exists e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \exists e.[\mathbf{seeing}(e) \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m})]]]\rangle}\ \mathrm{MRG}_1$$

Fig. 2. Example derivation for *Mary saw everyone leave*

$$(26)\ \frac{\texttt{everyone}:\ \langle \texttt{d}, \lambda k.\forall x.[\mathbf{person}(x) \to k(x)]\rangle \qquad \texttt{to leave}:\ \langle \texttt{=d}, \theta_{\mathbf{ag}}\rangle\langle \texttt{v}, \mathcal{P}_{\mathbf{leaving}}\rangle}{\texttt{everyone to leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge f(e')]]\rangle}\ \mathrm{MRG}_2$$

$$(25)\ \frac{\texttt{forbade}:\ \langle \texttt{v=}, \theta_{\mathbf{th}}\rangle\langle \texttt{=d}, \theta_{\mathbf{ag}}\rangle\langle \texttt{v}, \mathcal{P}_{\mathbf{forbidding}}\rangle \qquad \texttt{everyone to leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge f(e')]]\rangle}{\texttt{forbade everyone leave}:\ \langle \texttt{=d}, \theta_{\mathbf{ex}}\rangle\langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{forbidding}(e) \wedge \mathbf{th}(e) = e' \wedge f(e)]]]\rangle}\ \mathrm{MRG}_1$$

$$(26)\ \frac{\texttt{Mary}:\ \langle \texttt{d}, \lambda k.k(\mathbf{m})\rangle \qquad \texttt{forbade everyone leave}:\ \langle \texttt{=d}, \theta_{\mathbf{ex}}\rangle\langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{forbidding}(e) \wedge \mathbf{th}(e) = e' \wedge f(e)]]]\rangle}{\texttt{Mary forbade everyone leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{forbidding}(e) \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m} \wedge f(e))]]]]\rangle}\ \mathrm{MRG}_2$$

$$(25)\ \frac{\varepsilon:\ \langle \texttt{v=}, I\rangle\langle \texttt{c}, \mathbf{E!}\rangle \qquad \texttt{Mary forbade everyone leave}:\ \langle \texttt{v}, \lambda f.\forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \Sigma e.[\mathbf{forbidding}(e) \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m} \wedge f(e))]]]]\rangle}{\texttt{Mary forbade everyone leave}:\ \langle \texttt{v}, \forall x.[\mathbf{person}(x) \to \Sigma e'.[\mathbf{leaving}(e') \wedge \mathbf{ag}(e') = x \wedge \exists e.[\mathbf{forbidding}(e) \wedge \mathbf{th}(e) = e' \wedge \mathbf{ex}(e) = \mathbf{m})]]]\rangle}\ \mathrm{MRG}_1$$

Fig. 3. Example derivation for *Mary forbade everyone to leave*

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