Compositional Account of Event Quantification in Dependent Type Semantics

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1 Introduction: Event Quantification

Event semantics, where the logical form of a sentence contains an event variable and an existential quantifier binding the variable (an event quantifier), was first developed by Davidson [6]. Parsons [16] later reformulated Davidson's event semantics as Neo-Davidsonian event semantics to analyze thematic roles as functions that take event variables.

However, it is known that combining (Neo-)Davidsonian event semantics with Montague's treatment of quantification [15] may produce unexpected semantic interpretations. Consider sentence (1), which under Neo-Davidsonian event semantics[1] with **teach** : $\mathsf{e} \to \mathsf{e} \to \mathsf{t}$, has two possible interpretations: (2a) or (2b).

(1) John taught every student.

(2) (a) $\forall x(\mathbf{student}(x) \to \exists e(\mathbf{teach}(e) \wedge \mathbf{ag}(e) = \mathbf{j} \wedge \mathbf{th}(e) = x))$

(b) $\exists e(\mathbf{teach}(e) \wedge \mathbf{ag}(e) = \mathbf{j} \wedge \forall x(\mathbf{student}(x) \to \mathbf{th}(e) = x))$

The problem here is that when the event quantifier takes a wider scope, event semantics gives an incorrect interpretation as in (2b), which forces quantificational noun phrases to take scope over event quantifiers. De Groote and Winter [7] called this the *event quantification* problem. There have been several proposals regarding how to avoid such incorrect interpretations as (2b) [9, 2, 8, 22, 7, 5, 1, 13, 21].

2 Solution in Dependent Event Types

Among such proposed solutions, Luo and Soloviev [13] provided one with dependent event types (we will henceforth call this solution DET), which formalizes a treatment of the event semantics by using dependent types in Modern Type Theories [12, 1]. While there is only one semantic type (event type) for events in (Neo-)Davidsonian event semantics [6, 16], event types in DET depend on thematic roles of the events. For example, let agent and theme be the types of agents and themes, respectively. Then, for $\mathbf{a}$: agent and $\mathbf{t}$: theme, the dependent type $\mathsf{evtat}(\mathbf{a}, \mathbf{t})$ is the type of events whose agent is $\mathbf{a}$ and whose theme is $\mathbf{t}$. We can define functions $\mathbf{agent}_{\mathsf{at}}[\mathbf{a}, \mathbf{t}]$ and $\mathbf{theme}_{\mathsf{at}}[\mathbf{a}, \mathbf{t}]$ such that for any event e : $\mathsf{evtat}(\mathbf{a}, \mathbf{t})$, $\mathbf{agent}_{\mathsf{at}}[\mathbf{a}, \mathbf{t}](e) = \mathbf{a}$ and $\mathbf{theme}_{\mathsf{at}}[\mathbf{a}, \mathbf{t}](e) = \mathbf{t}$.

[1] In this paper, we write a thematic role function for an agent as **ag** and those for a theme as **th**, respectively.

In this analysis, events have a natural subtyping relationship between them. For example, the type $\mathsf{evtat}(\mathbf{a}, \mathbf{t})$ is a subtype of $\mathsf{evta}(\mathbf{a})$ for $\mathbf{a} : \mathsf{agent}$ and $\mathbf{t} : \mathsf{theme}$. The event types event, $\mathsf{evta}(\mathbf{a})$, $\mathsf{evtt}(\mathbf{t})$ and $\mathsf{evtat}(\mathbf{a}, \mathbf{t})$ have the subtyping relationships

$$\mathsf{evtat}(\mathbf{a}, \mathbf{t}) \leq \mathsf{evta}(\mathbf{a}) \leq \mathsf{event},$$
$$\mathsf{evtat}(\mathbf{a}, \mathbf{t}) \leq \mathsf{evtt}(\mathbf{t}) \leq \mathsf{event}.$$

In DET, the event quantification problem is explained by the ill-typedness of the incorrect semantic interpretation. We thus interpret (2a) as (3a), where the event type evtat is dependent on the agent and theme types.

(3) (a) $\forall x : \mathsf{entity}.(\mathbf{student}(x) \rightarrow \exists e : \mathsf{evtat}(\mathbf{j}, x).(\mathbf{teach}(e)))$

(b) (#) $\exists e : \mathsf{evtat}(\mathbf{j}, x).(\mathbf{teach}(e) \wedge \forall x : \mathsf{entity}.(\mathbf{student}(x))$

The incorrect interpretation (3b) is not available because x in $\mathsf{evtat}(\mathbf{j}, x)$, which is outside the scope of $\forall x$, is an undeclared free variable.

While DET offers a simple account for the event quantification problem, the previous work has not explained the lexicalization of semantic components and how to obtain their semantic representations, and it is unclear whether we can compositionally construct semantic representations of sentences from their syntactic structures.

In addition, DET wrongly blocks semantic interpretations involving frequency adverbs. Consider the following sentence:

(4) John taught two students three times.

This sentence can be true when John taught different pairs of students for each time. In this reading, the frequency adverb *three times* takes scope over the object noun phrase *two students*. In a compositional setting, this reading requires the adverb *three times* to be quantified outside the object noun phrase. However, since the event type is dependent on the theme in DET, the semantic representation (5) for the reading where the frequency adverb takes scope above the object noun phrase becomes ill-typed.

(5) (#) $\mathbf{three}(\lambda e : \mathsf{evtat}(\mathbf{j}, x).(\mathbf{teach}(e) \wedge \mathbf{two}(\lambda x : \mathsf{entity}.(\mathbf{student}(x)))))$

In summary, there are two issues in the solution to the event quantification problem in DET. First, it is not clear how to compositionally handle event quantification problems in dependent type theories. Second, DET fails to account for scope interactions between frequency adverbs and quantifiers.

3 Proposal

To resolve these issues, we propose a compositional account of the event quantification problem with Dependent Type Semantics (DTS) [4, 3] and Champollion's continuation semantics for event predicates [5]. DTS is an extended framework of discourse semantics based on Martin-Löf's intuitionistic type theory [14], which follows the constructive, proof-theoretic approach to semantics established by Sundholm [20] and Ranta [17]. We select Combinatory Categorial Grammar (CCG) [19] as a syntactic theory of DTS and adopt the version of DTS proposed in [3] as a semantic theory.

Example	CCG category	Semantic representation
John	NP	$\mathbf{j}$
student	N	$\lambda x.\mathbf{student}(x)$
taught	$S\backslash NP/NP$	$\lambda yxK.(e : \text{entity}) \times \mathbf{event}(e) \times \mathbf{teach}(e) \times (\mathbf{ag}(e) = x) \times (\mathbf{th}(e) = y) \times K(e)$
every$_{\text{OBJ}}$	$(S\backslash NP)\backslash(S\backslash NP/NP)/N$	$\lambda nPxK.(v : (x : \text{entity}) \times n(x)) \to P(\pi_1 v)xK$
two$_{\text{OBJ}}$	$(S\backslash NP)\backslash(S\backslash NP/NP)/N$	$\lambda nPxK.\mathbf{two}(n)(\lambda y.PyxK)$

Table 1: Lexical entries for our analysis. We omit the analysis of tense in this abstract.

$$\frac{\text{every}}{(S\backslash NP)\backslash(S\backslash NP/NP)/N : \lambda nPxK.(v : (x : \text{entity}) \times n(x)) \to P(\pi_1 v)xK} \quad \frac{\text{student}}{N : \lambda x.\mathbf{student}(x)}$$

$$\xrightarrow{>} (S\backslash NP)\backslash(S\backslash NP/NP) : \lambda PxK.((v : (x : \text{entity}) \times \mathbf{student}(x)) \to P(\pi_1 v)xK)$$

$$\frac{\text{taught}}{S\backslash NP/NP : \lambda yxK.(e : \text{entity}) \times \mathbf{event}(e) \times \mathbf{teach}(e) \times (\mathbf{ag}(e) = x) \times (\mathbf{th}(e) = y) \times K(e)}$$

$$\xrightarrow{<} S\backslash NP : \lambda xK.((v : (x : \text{entity}) \times \mathbf{student}(x)) \to (e : \text{entity}) \times \mathbf{event}(e) \times \mathbf{teach}(e) \times (\mathbf{ag}(e) = x) \times (\mathbf{th}(e) = \pi_1 v) \times K(e))$$

$$\frac{\text{John}}{NP : \mathbf{j}}$$

$$\xrightarrow{<} S : \lambda K.((v : (x : \text{entity}) \times \mathbf{student}(x)) \to (e : \text{entity}) \times \mathbf{event}(e) \times \mathbf{teach}(e) \times (\mathbf{ag}(e) = \mathbf{j}) \times (\mathbf{th}(e) = \pi_1 v) \times K(e))$$

$$\xrightarrow{cc} \bar{S}[dcl] : (v : (x : \text{entity}) \times \mathbf{student}(x)) \to (e : \text{entity}) \times \mathbf{event}(e) \times \mathbf{teach}(e) \times (\mathbf{ag}(e) = \mathbf{j}) \times (\mathbf{th}(e) = \pi_1 v) \times \top$$

Figure 1: CCG derivation and semantic composition for (1). The cc (continuation closure) rule is a unary rule to fill the argument K with the term $\lambda e.\top$ to make the semantic type for a declarative sentence type.

Table 1 shows lexical entries for our analysis. The source of the problem in DET lies in the fact that event types are dependent on thematic role types. Instead, we employ Champollion's analysis using event continuation [5] and interpret verbs as generalized existential quantifiers over events. In this analysis, the existential closure is put into the lexical entry of a verb, which forces the event quantification to take the lowest scope. We thus do not need to make the type **event**(e) dependent on thematic roles. Since some common nouns, such as *destruction* and *singing*, characterize events [16], we consider the type for the events as a subtype of **entity**, which can be represented as the Σ-type $(e : \text{entity}) \times \mathbf{event}(e)$ and treat both verbs and nouns as a set of entities. We can obtain the semantic composition for (1) according to the CCG derivation as in Figure 1.

Consider the sentence (4), which involves frequency adverbs. When the object noun phrase takes scope below the frequency adverb, the lexical entry for the adverb *three times* can be considered as (12).

(12) $[\![\text{three times}_{\text{OBJ}<\text{ADV}}]\!] = \lambda PxK.\mathbf{three}(\mathbf{event})(\lambda e.Px(\lambda e'.((e = e') \times K(e'))))$

Figure 2 shows that our analysis with this lexical entry provides a compositional account for the reading in which the adverb takes scope over the object noun phrase.

4 Conclusion and Future Work

We showed that the previous analysis of event semantics based on dependent event types has two issues: it does not define the process of semantic composition, and it does not explain interactions between quantifications of frequency adverbs and event quantification. We proposed a compositional semantics that combines dependent type semantics and event continuations, and demonstrated the process from syntactic structures to semantic representations for readings in which the object noun phrase takes scope below the frequency adverb.

Two open questions remain as interesting problems for future investigations. The first is a possible account for the reading where the object noun phrase takes scope above the frequency

$$\frac{\text{taught}}{S\backslash NP/NP} \quad \lambda yxK.(e:\text{entity})\times\textbf{event}(e)\times\textbf{teach}(e)\times(\textbf{ag}(e)=x)\times(\textbf{th}(e)=y)\times K(e)$$

$$\frac{\text{two}}{(S\backslash NP)\backslash(S\backslash NP/NP)/N} \quad \lambda nPxK.\textbf{two}(n)(\lambda y.PyxK)$$

$$\frac{\text{students}}{N} \quad \lambda x.\textbf{student}(x)$$

$$\xrightarrow{>} \quad (S\backslash NP)\backslash(S\backslash NP/NP) \quad \lambda PxK.\textbf{two}(\textbf{student})(\lambda y.PyxK)$$

$$\xrightarrow{<} \quad S\backslash NP \quad \lambda xK.\textbf{two}(\textbf{student})(\lambda y.(e:\text{entity})\times\textbf{event}(e)\times\textbf{teach}(e)\times(\textbf{ag}(e)=x)\times(\textbf{th}(e)=y)\times K(e))$$

$$\frac{\text{three times}}{(S\backslash NP)\backslash(S\backslash NP)} \quad \lambda PxK.\textbf{three}(\textbf{event})(\lambda e.Px(\lambda e'.((e=e')\times K(e'))))$$

$$\xrightarrow{<} \quad S\backslash NP \quad \lambda xK.\textbf{three}(\textbf{event})(\lambda e.\textbf{two}(\textbf{student})(\lambda y.(e':\text{entity})\times\textbf{event}(e')\times\textbf{teach}(e')\times(\textbf{ag}(e')=x)\times(\textbf{th}(e')=y)\times(e=e')\times K(e')))$$

$$\frac{\text{John}}{NP} \quad \textbf{j}$$

$$\xrightarrow{<} \quad S \quad \lambda K.\textbf{three}(\textbf{event})(\lambda e.\textbf{two}(\textbf{student})(\lambda y.(e':\text{entity})\times\textbf{event}(e')\times\textbf{teach}(e')\times(\textbf{ag}(e')=\textbf{j})\times(\textbf{th}(e')=y)\times(e=e')\times K(e')))$$

$$\xrightarrow{cc} \quad \overline{S}[dcl] \quad \textbf{three}(\textbf{event})(\lambda e.\textbf{two}(\textbf{student})(\lambda y.(e':\text{entity})\times\textbf{event}(e')\times\textbf{teach}(e')\times(\textbf{ag}(e')=\textbf{j})\times(\textbf{th}(e')=y)\times(e=e')\times\top))$$

Figure 2: CCG derivation and semantic composition for (4) when the object noun phrase takes scope below the frequency adverb.

adverb. To obtain this reading, the three operator must take scope under *two* and over the existential quantification of the event. However, it is difficult to explain this reading by just providing another lexical entry for *three times* that is different from (12). The second question is how to account for different readings for plural noun phrases. Sentence (4) has not only scope ambiguity for the frequency adverb *three times* but also distributive, collective, and cumulative readings for the plural object *two students*. Our current proposal fails to explain the cumulative reading, which becomes true if John taught Student A, Student B, and Student A again. There have been different accounts for plurality [11, 18, 10], so one possible way of obtaining the cumulative reading is to explore how to combine these accounts and DTS.

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