An event semantics with continuations for incremental interpretation

Abstract

This paper presents a method to construct event semantic representations incrementally from left to right. The proposed theory focusses on the interaction between events and other scope taking expressions, in particular quantificational DPs and adverbials that are sensitive to aspect. Psycholinguistic experiments have revealed that semantic mismatches can be detected as early as their lexical triggers are encountered, without waiting for a complete semantic or syntactic representation. Our theory thus provides for "incomplete" representations that nonetheless allow for an immediate explanation of such mismatches, right at the point where left to right parsing detects the offending triggers.

Viewed from a broader perspective, our framework can be seen as a logical background for theories of semantic parsing in general. In contrast to existing implementations of incremental interpretation, we only employ a single compositional processing rule, namely functional composition of only one logical type of expressions. On the other hand, for this (otherwise unmatched) uniformity to work, we rely on advanced semantic techniques like continuations, dynamic binding, and unrestricted β-reduction (cf. Barker 2002, Gronendijk & Stokhof 1991, Klein & Sternefeld 2013, respectively). In the context of adverbials, these methods can be shown to interact in a non-trivial way with the mereology of events as proposed in Krifka (1992).

Keywords: Incremental semantic interpretation; real-time interpretation; event semantics; continuation semantics; grammatical and lexical aspect; scope of logical operators; mereology

1   Introduction

Standard semantic theories derive the interpretation of sentences in a holistic fashion: while calculating denotations in parallel to syntactic structure, in a more or less compositional way, truth values and inferences can only be calculated when the sentence is complete. This property of most formal semantic theories makes it impossible to directly apply them to psycho- and neurolinguistic work on language perception. In order to

model the semantic representations that underly the incremental (left to right) construction of sentence and discourse meaning during online interpretation, it seems essential to calculate semantic representations for non-constituents and to be able to derive logical consequences from only partial representations, i.e. incomplete constituents.

To illustrate the need for such a theory, consider the sentence beginnings in (1) which all involve the interpretation of non-constituents. Examples like these (taken from German, English, and Russian) have been shown, or can be expected, to lead to immediate processing difficulty right at the bold-faced words relative to the minimally different variants shown in parentheses.

(1) a. Eine Katze **streichelte**...   (Ein Mädchen **streichelte**...)
         A cat petted...   (A girl petted...)
     b. Kein Student hat **nicht**...   (Alle Studenten haben **nicht**...)
         No student has not...   (All students have not...)
     c. Dass keinen Studenten **jeder Professor** ...   (Dass einen S. **jeder P.** ...)
         That no student$_{object}$ every professor$_{subject}$...   (That one s. every p. ...)
     d. Morgen **hatte**...   (Gestern **hatte**...)
         Tomorrow had...   (Yesterday had...)
     e. Put the apple on the towel **into the box**...   *(two- vs one-referent context)*
     f. Drei Stunden lang **gewann**...   (Vor drei Stunden **gewann**...)
         For three hours won...   (Three hours ago won...)
     g. Celych tri časa **vyigrala**...   (Tri časa nazad **vyigrala**...)
         For three hours won$_{perfective}$...   (Three hours ago won$_{perfective}$...)

Sentence fragment (1-a) illustrates thematic disambiguation of local structural ambiguity. *eine Katze* (*a cat*) is per default interpreted as the agent and subject of the sentence, but the verb *streicheln* is incongruent with this analysis because it presupposes a human agent. Accordingly, the DP *a cat* has to be interpreted as the theme argument, hence the object of the verb. A number of psycholinguistic studies have demonstrated incremental processing or even anticipation of the upcoming argument right at transitive verbs (Altmann & Kamide 1999, DeLong, Urbach & Kutas 2005, Knoeferle, Crocker, Scheepers & Pickering 2005, Berkum, Brown, Zwitserlood, Kooijman & Hagoort 2005). This effect cannot be modeled in an incremental fashion since the subject and the transitive verb do not form a constituent and can thus not be incrementally composed with each other. [1]

The next two examples illustrate incremental processing of DPs and negation. (1-b) combines the negative quantificational determiner *kein* (*no*) with negation—a case that

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[1] There are frameworks such as Combinatorial Categorial Grammar (CCG, e.g., Steedman 2001), Tree Adjoining Grammar supplemented with compositional semantics (TAG and LTAG, Joshi & Schabes 1997, Joshi, Kallmeyer & Romero 2007, respectively) and Dynamic Syntax (Kempson, Meyer-Viol & Gabbay 2000, Cann, Kempson & Marten 2005) that can deal with examples such as these. We will comment briefly on alternative theories in section 2.4.

should be more complex than the example in parentheses with the non-negative determiner *every*. As in the previous examples, standard semantic analyses do not allow us to compose a DP with negation without having the main predicate in the scope of negation. The same holds for the configuration illustrated in (1-c) in which the processing system has to decide on a scope reading without yet having any verbal information. Even though it is unclear whether such scope interpretation effects are actually incremental (Bott & Schlotterbeck (2015) provide preliminary evidence that they are not), we would like a semantic formalism flexible enough to spell out compositional analyses in an incremental fashion.

Turning to the semantics of tense and aspect, the same holds for (1-d). In this example, semantic interpretation is impossible because the past morphology of the auxiliary is incompatible with the adverb *morgen* (*tomorrow*), which locates the reference time in the future. Processing difficulty in examples like these has, for instance, been shown in ERPs studies by Baggio (2008) and Bott (2010, ch. 8). Again within standard semantic theories, it is not clear how we could model the incremental tense mismatch in this example.

Example (1-e) is a famous example from the processing literature (Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy 1995). The derivation below will illustrate how the proposed semantic framework can be extended beyond event modification to nominal modifiers. Up to the PP *on the towel*, the sentence is ambiguous between a directional, VP-attachment reading (the towel serves as goal of the put event) and a locative, NP-attachment reading (where the apple is located on the towel). Depending on whether the context contains a single apple or multiple apples, studies in the visual world paradigm have shown an immediate preference for VP attachment in the one-referent context and a preference for NP attachment in the two-referent context. Furthermore, sentences such as (1-e) uttered in a one-referent context lead to immediate processing costs when a second directional PP (*into the box*) is encountered further downstream the sentence. This cost indicates reanalysis from the VP-attachment to the NP-attachment reading. Modifier attachment ambiguities have played a key role in the *Referential Theory* (Crain & Steedman 1985, Altmann & Steedman 1988), and a formal incremental semantic analysis has been worked out by Steedman (2001).

Finally, we will consider a contrast in processing aspectual mismatch in German and Russian (reported in Bott & Gattnar 2015). The test case involves achievement verbs such as *win*, which generally do not allow for modification by durative adverbials such as *for two hours*. What makes this an interesting test case is that German and Russian are two languages with relatively free word order but with very different aspectual systems. The relevant examples are provided in (1-f) and (1-g). Russian readers showed immediate mismatch effects while reading the perfectively marked achievement verb, whereas German readers only experienced aspectual mismatch after having read the complete VP with all arguments—e.g. by adding *the fight*). The semantic derivation of these examples will show that the observed cross-linguistic difference is expected once we adopt

an incremental semantic analysis of the constructions under investigation. Thus, what at first sight may look like a non-incremental effect in the case of aspectual interpretation in German turns out to be fully consistent with an incremental analysis. The example thus highlights what we actually gain from formal incremental semantic analysis: precise predictions about when incremental semantic effects should show up during left to right processing. Moreover, the example is instructive in another respect: as the analysis of the Russian example (1-g) in section 5 reveals, the data exemplify yet another case in which presuppositions have to be computed in a scope-independent way.

As evidenced by the literature cited, these observations are not new; nonetheless a mechanism that allows deductive reasoning before the propositional level is reached is still a desideratum, not only in psychology but also in formal pragmatics, when it comes to compute the local effects of implicatures.[2] Hardly any existing formal model is flexible enough to properly deal with incremental interpretation in all of these cases. The theory proposed in this paper is an attempt to provide for a format that deals with various aspects of meaning in a Neo-Davidsonian setting (see, e.g., Parsons 1990), including the compositional interpretation of tense, aspect and lexical aspect or Aktionsart. We show in detail how the above mentioned mismatches can be derived in a local manner. Moreover, we hope that the present proposal extends to other areas where composition of non-constituents is required. We would like to emphasize that the proposed system is first and foremost a semantic theory intended to provide us with left-to-right derivations. In itself, it is not intended as a processing theory. Crucially, we have to remain agnostic about whether semantic interpretation is in fact incremental through and through for all kinds of linguistic phenomena. In the following, we will refer the reader to central psycholinguistic findings on the timing of semantic interpretation and introduce a case study which served as our personal starting point for the work reported in this paper. When working out the system, however, we encountered a number of examples that are interesting in terms of incrementality. Many of them have, to our knowledge at least, never been tested in online experiments. We nevertheless decided to include them into this article because we hope that this paper will promote further experimental investigations.

The paper is structured as follows. Section 2 introduces the general framework. The proposed theory will then be applied to DPs in section 3 and to the examples (1-a)-(1-d)

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[2]A number of online studies on the time-course of scalar implicature comprehension (e.g. Grodner, Klein, Carbary & Tanenhaus 2010, Breheny, Ferguson & Katsos 2013) suggest that the implicature *some but not all* is immediately computed when *some* is encountered even in yet incomplete sentences such as *The man has poured some. . . .* In Neo-Gricean accounts scalar implicatures are generally derived via inferences depending on logically stronger alternatives (Grice 1975, Horn 1972). However, the involved entailment relations are stated in terms of complete sentences. Similarly for the defaultist view on scalar implicatures (Chierchia 2004). Here, the derivation of implicatures strongly depends on the larger sentence context, in particular, whether the scalar expression appears in a monotone increasing or decreasing environment. To decide whether this is the case, a representation of the partial sentence is required. We assume that something similar also holds with respect to Relevance Theory (Sperber & Wilson 1986), too. To us, at least, it is not obvious how the relevance or informativity of a partial sentence should be evaluated.

in section 4. Section 5 presents the results of a case study that investigates the time course of aspectual interpretation in sentences like (1-f) and (1-g). It includes a subsection 5.2 that introduces the required concepts of lexical and grammatical aspect before subsection 5.3 presents detailed semantic derivations of the above mentioned examples. Section 6 concludes the paper.

2   Incremental interpretation: The basics

Kim & Osterhout (2005) observed mismatch effects right at the transitive verb well before the object, in response to (2-a) relative to (2-b). This mismatch is due to the fact that the subject *the hearty meal* is semantically not suited to fill the agent role of a devour event.

(2)   a.   #The hearty meal was devouring . . .
       b.   The hearty meal was devoured . . .

What makes it difficult to model this mismatch effect is that we are dealing with the partial sentence in (2-a) which in standard semantic theory requires composition of the verb with its *internal* argument *before* composition with the subject is possible. However, within the framework of event-semantics, it is rather obvious what the resulting interpretation of (2-a) should be, namely (3). If we were able to derive (3), the semantic difficulty would be fully predictable once we acknowledge that the agent role can only be filled by animate entities.

(3) $[\![$subject + verb$]\!] = \exists e(\textbf{devour}(e) \wedge \text{agent}(e, \textbf{the hearty meal}))$

The function $[\![.]\!]$ denotes the translation function from natural language into a two sorted predicate logic with lambda abstraction. Although event semantics is particularly well-suited to represent partial information, we would like to stress that this is not our reason to use (Neo-Davidsonian) event semantics in the first place. In fact, almost everything that follows would be compatible with any other framework, except for our treatment of grammatical and lexical aspect in section 5.

2.1   Events, continuations and functional composition

In the following, we will augment a Neo-Davidsonian event semantics with continuations (see Barker 2002, de Groote 2006, Barker & Shan 2008, Barker & Shan 2014) by extending the theory of Champollion (2015). We will start with an incremental analysis (ignoring tense and aspect for now) of the German sentences (4-a) and (4-b) which illustrate flexible word order: subject-verb-object (4-a) vs. object-verb-subject (4-b).

(4)   a.   Der Boxer   gewinnt die Runde.
           The boxer$_{subject}$ wins   the round$_{object}$.

b. Die Runde   gewinnt der Boxer.
The round$_{object}$ wins   the boxer$_{subject}$.
'the boxer wins the round.'

We follow Champollion's (2015) suggestion that verbs directly introduce existential quantification over events with narrowest scope. We add to this that all lexical entries contain two open slots: one variable within the scope of the event quantifier in order to introduce further information about this event further downstream the sentence, and another variable outside the scope of the existential event quantifier. The latter is required by material in a sentence which, like nominal quantifiers, take scope over the event predication. The general format of a verb's information is:

(5) $\lambda c_{\langle t,t\rangle}\lambda p_{\langle t\rangle}.c(\exists e(\mathbf{verb}(e) \wedge p))$

Here, c of type $\langle t, t\rangle$ is a variable for continuations with the existential quantifier in its scope. p of type t is a variable for continuations within the scope of the existential quantifier. The latter assumption sounds a bit awkward since information about e will have the form $P(e)$, but beta reduction (or lambda conversion) of $P(e)$ by λp into the scope of the binder ($\exists e$) is usually not permitted. Throughout the paper, we assume the semantic framework of *Unrestrained β-Reduction* explained in Klein & Sternefeld (2013), where this restriction is lifted by a more involved interpretation method. We cannot go into details here but simply assume that β-reduction is permitted whenever it is possible, without the restrictions concerning free and bound variables. The general idea behind the theory is outlined in Appendix A.

Next we consider arguments of a verb, e.g., quantifying expressions like *every man* or more generally *every N*. We assume that in syntax the quantifying expression combines with thematic roles *agent*(e, x) or *theme*(e, x). We show the result of this combination in case of [*every N*]$_i$ in (6) and [*a M*]$_j$ in (7), where R is short for a thematic role or relation:

(6) $\lambda c_{\langle t,t\rangle}\lambda p_{\langle t\rangle}\forall x_i(N(x_i) \rightarrow c(p \wedge R(e, x_i)))$

(7) $\lambda c_{\langle t,t\rangle}\lambda p_{\langle t\rangle}\exists x_j(M(x_j) \wedge c(p \wedge R(e, x_j)))$

For example, the DP *a cat* from example (1-a) translates as:

(8) $\lambda c_{\langle t,t\rangle}\lambda p_{\langle t\rangle}\exists x_j(\mathbf{cat}(x_j) \wedge c(p \wedge \mathrm{agent}(e, x_j)))$

Note that this translation contains e as a free variable; we must assume that this is the same variable as the event variable of the verb. As will be shown below, keeping track of variables is crucial in the present system, but for the sake of simplicity, we use the symbol e as a designated variable for events and will not consider constructions with more than one verb. We will come back to the internal composition within the DP below.

Let us now consider the rule that combines whole DPs and verbs ignoring scope for the moment. It is very simple:

(9) $\llbracket DP + V \rrbracket = \lambda c_{\langle t,t \rangle}[DP[V(c)]]$.

Combining (8) with *petted* by (9) is shown in (10):

(10) $\lambda c_{\langle t,t \rangle}[\lambda c_{\langle t,t \rangle}\lambda p_{\langle t \rangle}\exists x_j(\mathbf{cat}(x_j) \wedge c(p \wedge \text{agent}(e,x_j)))[\lambda c_{\langle t,t \rangle}\lambda p_{\langle t \rangle}(c(\exists e(\mathbf{petted}(e) \wedge$
$p))(c)]]$
$= \lambda c_{\langle t,t \rangle}[\lambda c_{\langle t,t \rangle}\lambda p_{\langle t \rangle}\exists x_j(\mathbf{cat}(x_j) \wedge c(p \wedge \text{agent}(e,x_j)))[\lambda p_{\langle t \rangle}(c(\exists e(\mathbf{petted}(e) \wedge p)))]]$
$= \lambda c_{\langle t,t \rangle}[\lambda p_{\langle t \rangle}\exists x_j(\mathbf{cat}(x_j) \wedge [\lambda p_{\langle t \rangle}(c(\exists e(\mathbf{petted}(e) \wedge p)))](p \wedge \text{agent}(e,x_j))]$
$= \lambda c_{\langle t,t \rangle}[\lambda p_{\langle t \rangle}\exists x_j(\mathbf{cat}(x_j) \wedge c(\exists e(\mathbf{petted}(e) \wedge (p \wedge \text{agent}(e,x_j)))))]$
$= \lambda c_{\langle t,t \rangle}\lambda p_{\langle t \rangle}\exists x_j(\mathbf{cat}(x_j) \wedge c(\exists e(\mathbf{petted}(e) \wedge p \wedge \text{agent}(e,x_j))))$

The last two steps of the derivation involves unconstrained beta-reduction plus elimination of parentheses. Note that the composition rule in (9) is an instance of function composition in Combinatorial Categorial Grammar (Dowty 1988, Steedman 2001):

(11) $X/Y : f \quad Y/Z : g \Rightarrow_{\mathbf{composition}} X/Z : \lambda x.f(g(x))$

In general, the two linear possibilities exemplified in (9) can result in two different scopal construals—an ambiguity that can be captured by generalizing (9) as shown in (12), where (12-a) gives some expression α linear scope (notation: $>$) over β, whereas (12-b) gives β inverse scope over the preceding α (notation: $<$); cf. also Barker (2002):

(12) a. $\llbracket \alpha > \beta \rrbracket = \lambda c_{\langle t,t \rangle}[\llbracket \alpha \rrbracket[\llbracket \beta \rrbracket(c)]]$
      b. $\llbracket \alpha < \beta \rrbracket = \lambda c_{\langle t,t \rangle}[\llbracket \beta \rrbracket[\llbracket \alpha \rrbracket(c)]]$

In order to see how this works, we will derive a semantic representation for *A boxer wins* (cf. (4-a)). Before going into the details of the analysis, we offer some general considerations that will help to simplify the derivations in the rest of the paper.

As a notational convention without theoretical significance let us tentatively assume that lexemes are numbered consecutively from left to right. In order to enhance readability of the following formulas, we furthermore assume that this index is the index of the lexeme's continuation variable. When combining two strings $a_1, ...a_n$ and $b_{n+1}, ...b_{n+m}$, the continuation variable in (12) has, by convention, the index $n+m$:

(13) a. $\llbracket \alpha > \beta \rrbracket = \lambda c_{n+m}[\llbracket a_1, ...a_n \rrbracket[\llbracket b_{n+1}, ...b_{n+m} \rrbracket(c_{n+m})]]$
      b. $\llbracket \alpha < \beta \rrbracket = \lambda c_{n+m}[\llbracket b_{n+1}, ...b_{n+m} \rrbracket[\llbracket a_1, ...a_n \rrbracket(c_{n+m})]]$

Since all constituents and lexemes have the prefix $\lambda c_i \lambda p$, we can simplify (13) in the following manner: Given that α and β have the form $\lambda c_n \lambda p A$ and $\lambda c_{n+m} \lambda p B$ respectively, the linear construal in (13-a) is derived by applying β (ie. $\lambda c_{n+m}\lambda p B$) to c_{n+m}. The result is $\lambda p B$. Since this is the argument of the first constituent $\lambda c_n...$, the result after β-reduction is (14):

(14) $\lambda c_{n+m}\lambda p(A[c_n/\lambda p B])$

where $[x/y]$ means that x is replaced by y.

In the reverse construal, the result is:

(15) $\lambda c_{n+m}\lambda p(B[c_{n+m}/\lambda pA[c_n/c_{n+m}]])$

For example, in the derivation of *a boxer wins . . .* we immediately apply the linear reduction in (16-c):

(16)   a. $[\![a_1\ boxer_2]\!] = \lambda c_2 \lambda p \exists x(\mathbf{boxer}(x) \wedge c_2(p \wedge \mathrm{agent}(e,x)))$

     b. $[\![win_3]\!] = \lambda c_3 \lambda p(c_3(\exists e(\mathbf{win}(e) \wedge p)))$

     c. $[\![a_1\ boxer_2 > wins_3]\!]$
        $= \lambda c_3[\lambda p \exists x(\mathbf{boxer}(x) \wedge [\lambda p.c_3(\exists e(\mathbf{win}(e) \wedge p))](p \wedge \mathrm{agent}(e,x)))]$
        $= \lambda c_3 \lambda p \exists x(\mathbf{boxer}(x) \wedge c_3(\exists e(\mathbf{win}(e) \wedge (p \wedge \mathrm{agent}(e,x)))))$

Next, the reader should verify that the indices of c do not really play a crucial role in the derivation; in fact, what we do is replace the c-variable of the scope taking element by the λp-prefixed argument. So if $\alpha = \lambda c \lambda p A$ applies to $\beta = \lambda c \lambda p B$, the result $\lambda c.\alpha(\beta(c))$ is (17-a), and the reversal construal is (17-b):

(17)   a. $\lambda c \lambda p A[c/\lambda p B]$

     b. $\lambda c \lambda p B[c/\lambda p A]$

We can therefore dismiss with all indeces of continuations and jump immediately to the reductions in (17).

Let us now show how (16) can be updated with a DP in object position, e.g. *every round*. First look at the derivation of the inverse interpretation:

(18) $[\![every\ round]\!] = \lambda c \lambda p \forall y(\mathbf{round}(y) \to c(p \wedge \mathrm{theme}(e,y)))$

(19) $[\![a\ boxer\ wins < every\ round]\!] = \lambda c[[\![every\ round]\!][[\![a\ boxer\ wins]\!](c)]]$
     $= \lambda c[\lambda p \forall y(\mathbf{round}(y) \to [\lambda p \exists x(\mathbf{boxer}(x) \wedge c(\exists e(\mathbf{win}(e) \wedge p \wedge \mathrm{agent}(e,x))))](p \wedge \mathrm{theme}(e,x)))]$
     $= \lambda c \lambda p \forall y(\mathbf{round}(y) \to \exists x(\mathbf{boxer}(x) \wedge c(\exists e(\mathbf{win}(e) \wedge (p \wedge \mathrm{theme}(e,y) \wedge \mathrm{agent}(e,x))))))$

The variables c and p can be eliminated by applying the trivial continuations $\lambda p.p$ of type $\langle t,t\rangle$ and the verum $\top$ of type $\langle t\rangle$ to the functions above. We thus get the intended reading without continuation and scope variables.

(20) $[\lambda c \lambda p \forall y(\mathbf{round}(y) \to \exists x(\mathbf{boxer}(x) \wedge c(\exists e(\mathbf{win}(e) \wedge p \wedge \mathrm{theme}(e,y) \wedge \mathrm{agent}(e,x)))))](\lambda p.p)(\top)$
     $= \forall y(\mathbf{round}(y) \to \exists x(\mathbf{boxer}(x) \wedge [\lambda p.p](\exists e(\mathbf{win}(e) \wedge \top \wedge \mathrm{theme}(e,y) \wedge \mathrm{agent}(e,x)))))$
     $= \forall y(\mathbf{round}(y) \to \exists x(\mathbf{boxer}(x) \wedge \exists e(\mathbf{win}(e) \wedge \mathrm{theme}(e,y) \wedge \mathrm{agent}(e,x))))$

The example (20) shows that there is a simple correspondence between continuation semantics and ordinary semantic values. Henceforth we will use this correspondence to evaluate the truth of terms with continuation variables directly. To do so, we just have to ignore the variables c and p and evaluate the remainder of the formula.

(21) Truth of formulae with continuation variables: A formula ϕ with the prefix $\lambda c \lambda p$ is true iff $\phi(\lambda p.p)(\top) = 1$.

It is assumed that at each point of a derivation truth and consistency of a fragment can be checked by applying (21).

2.2 Dynamic binding of event variables

It remains to account for the linear reading of *A boxer wins every round*. Before presenting our analysis, let us look more closely at the general pattern of scope interactions. For the small fragment included in the present paper, any sentence representation can be split up into two parts. We refer to the first part as the quantifier prefix (QP); here relative scope is essential. The second part contains the event predication (EP), proper. Since all parts of a complex event predication are combined conjunctively, they do not take scope over each other. The c-variables provide elaboration possibilities of the sentence's quantifier prefix, and p-variables introduce slots used to elaborate the event predication. The event quantifier and the event predicate introduced by the verb separate these two domains from each other: $QP(\exists e(\text{verb}(e) \wedge EP))$.

The general idea is that any lexical item can contribute to the quantifier prefix and/or the event predication of a sentence. Leaving the special case of verbs aside, which has already been illustrated above, we can abstract from particular lexical items. Let ϕ_i and ϕ_j be arbitrary expressions with quantifier prefixes QP_i and QP_j and event predications EP_i and EP_j, respectively.

(22) a. $[\![\phi_i]\!] = \lambda c_i \lambda p_i (QP_i(c_i(\ldots p_i \wedge EP_i)))$
      b. $[\![\phi_j]\!] = \lambda c_j \lambda p_j (QP_j(c_j(\ldots p_j \wedge EP_j)))$

Considering expressions in this rather abstract format, the results of the linear and the inverse composition rules are as follows:

(23) a. $[\![\phi_i > \phi_j]\!] = \lambda c[\lambda p.QP_i(QP_j(c(\ldots(\ldots p \wedge EP_i) \wedge EP_j)))]$
      b. $[\![\phi_i < \phi_j]\!] = \lambda c[\lambda p.QP_j(QP_i(c(\ldots(\ldots p \wedge EP_j) \wedge EP_i)))]$

Let us now return to our example *A boxer wins* + *every round*, assuming that *A boxer wins* has wide scope. According to the above format, this corresponds to:

(24) $\lambda c \lambda p(\text{a boxer}_i(\text{every round}_j(c(\ldots \exists e(\textbf{wins}(e) \wedge p \wedge \text{agent}(e, x_i)) \wedge \text{theme}(e, x_j)))))$

Now, considering the relation between $\exists e$ and EP_j ($= \text{theme}(e, x_j)$), it turns out that the

quantifier cannot bind the event variable in EP_j. It is for this reason that we resort to the theory of *Dynamic Conjunction* and *Dynamic Binding* as defined in Gronendijk & Stokhof (1991). In such a system, $(\exists x \alpha \wedge \beta)$ is equivalent to $\exists x(\alpha \wedge \beta)$, and it is this equivalence that will be exploited in our derivations. [3] To complete the analysis, we fill in the missing parts of (24):

(25) $\lambda c \lambda p(\text{a boxer}_i(\text{every round}_j(c(\ldots \exists e(\textbf{wins}(e) \wedge p \wedge \text{agent}(e, x_i)) \wedge EP_j)))) =$
     $\lambda c \lambda p(\text{a boxer}_i(\text{every round}_j(c(\exists e(\textbf{wins}(e) \wedge p \wedge \text{agent}(e, x_i) \wedge EP_j))))) =$
     $\lambda c \lambda p(\text{a boxer}_i(\text{every round}_j(c(\exists e(\textbf{wins}(e) \wedge p \wedge \text{agent}(e, x_i) \wedge \text{theme}(e, x_j)))))) =$
     $\lambda c \lambda p \exists x_i(\textbf{boxer}(x_i) \wedge (\forall x_j(\textbf{round}(x_j) \rightarrow (c(\exists e(\textbf{wins}(e) \wedge p \wedge \text{agent}(e, x_i) \wedge \text{theme}(e, x_j)))))))$

2.3   Some remarks on parsing strategies

Even though we are not concerned with syntactic parsing here, we would like to add a few comments on the syntactic representations underlying the derivations just sketched. The proposed semantic system makes use of two properties required to be specified in the input to semantic interpretation: a) the linear order of the incoming expressions and b) their relative scope. The proposed theory is thus fully compatible with any parsing theory as long as it provides us with fully-connected, scope-disambiguated parse trees. If we further assume that the semantic processor assigns linear scope per default, semantic processing can, in principle, proceed entirely independently of structural parsing. This flexibility guarantees that the proposed compositional machinery is compatible with serial and modular accounts of syntactic parsing (e.g., Frazier 1987) as well as parallel, non-modular parsing theories (e.g., McRae, Spivey-Knowlton & Tanenhaus 1998), which crucially rely on the assumption that the semantic evaluation of complex meaning forms a constraint on its own and can proceed independently of syntactic analysis. Such constraints have been called combinatorial constraints (MacDonald & Seidenberg 2006). However, the underlying combinatorial semantics has never been worked out formally. For combinatorial constraints to work independently from syntax, we clearly have to add further assumptions. Just to name two:

(26)   a.   Default scope: use the compositional rule for linear scope, unless there is

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[3] The reader may wonder why the proposed system makes use of both, unrestrained β-reduction **and** dynamic binding. It is important to note that these two theories relate to issues that are strictly orthogonal to each other. (A) Dynamic binding has a dynamic notion of conjunction but unrestrained β-reduction is a conservative extension of predicate logic and therefore involves the classic notion of conjunction. (B) Dynamic predicate logic interprets variables in the classic way, i.e. in terms of variable assignment functions. This is independent of whether the interpretation of variables depends on only one variable assignment or on two as is the case in dynamic predicate logic. By contrast, the interpretation of variables in a predicate logic with unrestrained β-reduction is far more complex. It is therefore impossible to implement unrestrained β-reduction within dynamic predicate logic. However, the analysis of the examples discussed so far shows that we actually need in fact both, dynamic conjunction as well as unrestrained β-reduction.

evidence to the contrary (e.g. variable binding, cf. (27)).

b. Thematic assignment: assign thematic roles in the order *agent>patient>*...,
unless there is evidence to the contrary (e.g. case marking).

As the present framework of unrestrained β-reduction explicitly allows the pure merge of two strings to compositionally establish a semantic binding relation, this gives rise to the following grammatical constraint that also severely restricts scopal options:

(27) Variable Binding: If one linearization results in binding but the reverse linearization does not, only the former is grammatical.

The *Variable Binding Constraint* will only become relevant in the next section; cf. derivation (31). All of the examples analyzed so far satisfied this constraint independently of which scope rule was applied. Thus, we assume that all of the examples discussed so far involved *Default Scope* except those where we explicitly assumed an inverse scope interpretation.

We would like to point out that in most cases inverse scoping requires some additional device that—on our account—has to be an integral part of the semantic parser: as illustrated in (19), we first calculate a representation for *a boxer wins*, which must be stored in some storing device in order to be able to calculate a representation for *every round*, after which the latter can be applied to the material retrieved from this stack. The reason for this is that wide scope material may itself be complex and must be assembled first before we can give it inverse wide scope. We therefore assume that, in order to deal with inverse scope, the semantic parser—though proceeding from left to right—sometimes has to store material in working memory: by interrupting its left to right mode it needs to access working memory because it needs to take in postponed material that will get narrow scope. It follows that, per default, inverse scope interpretations incur greater costs than linear interpretations. This claim has been corroborated in experimental research on online resolution of quantifier scope (Anderson 2004, Bott & Schlotterbeck 2015).

2.4 Comparison with other frameworks

Obviously, the proposed system is intimately tied to the format of event semantic formulas (with one event argument). This feature sets it clearly apart from other semantic theories that are able to model incremental interpretation as, for instance, the CCG framework proposed by Steedman (2001). Another point of divergence is that in Steedman's account the forward and backward composition rules are just one compositional pair of rules amongst others, whereas in the proposed framework composition is the only rule (of course at the cost of using advanced techniques like unrestrained β reduction and dynamic interpretation). We have to point out, though, that the empirical coverage of the theories is yet very different, so it has to be seen how far we will get with the system proposed here. Finally, the treatment of quantifiers is very different. Whereas in the quantification theo-

ries of Steedman (2001) and in particular Steedman (2012) only the universal quantifier is a generalized quantifier, and existential quantification is dealt with via Skolem functions, we employ both universal and existential quantification in the form of quantifiers from first-order logic. This conservative stance might have its limits, which are beyond the scope of this paper.

A brief remark may be in order as to why we modified the event quantification framework of Champollion (2015) instead of the alternative proposal by Beaver & Condoravdi (2007) (see also Eckardt (2010) and Winter & Zwarts (2011) for similar accounts). They proposed a system called *Linking Semantics* which provides a slightly different compositional analysis of the interaction of events and quantification, also without the need for covert movement. However, in their analysis they moved away from the classic Davidsonian treatment of action sentences employing event arguments. This is the reason why we chose Champollion's (2015) and not Beaver and Condoravdi's analysis as the starting point for our incremental event semantics. Our primary interest consists in the incremental construction of traditional (Neo-)Davidsonian event semantic representations. Moreover, Champollion (2015) presents two arguments against Beaver and Condoravdi concerning entailment relations between modified action sentences. He concludes that facts about verbal modification remain a strong motivation for the standard Davidsonian analysis. We cannot go into details here but refer the interested reader to the discussion in Champollion (2015, section 5).

3   The internal makeup of DPs

We assume that in each DP (as well as in PPs) thematic roles are introduced separately from their actual content and occupy the dedicated syntactic positions *agent* [ag] and *theme* [th] (see Champollion 2015 for a similar proposal) The DP *a boxer* bearing the agent role has the structure in (28). The agreement of indices guarantees that the quantifier, the restrictor and the thematic role involve the same variable x_i.

(28)

```
                DP₁
              /      \
          DP₂        [ag]ᵢ
         /    \
        D      NP
        |      |
        aᵢ    boxerᵢ
```
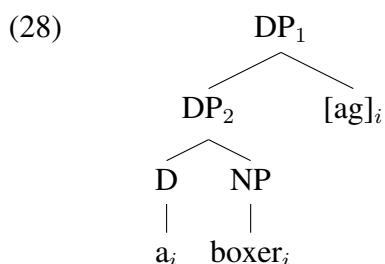
Coindexation with i is essential and can be independently justified by the considerations in Appendix B. Note that determiners are "real" quantifiers, i.e. they have quantificational force in being able to bind variables (usually after some unrestrained β-reduction), as opposed to "generalized" quantifiers which are relations between sets and lack quantificational force. More precisely, we treat natural language determiners like *every* and

some parallel to expressions like $\forall$ and $\exists$ in classical logic, with the decisive twist that these expressions are not treated syncategorematically, as in standard logic, but as genuine semantic objects with a compositional semantics of their own; cf. Chapter 10 in Zimmermann & Sternefeld (2013). As a matter of terminology, one might thus say that, if genuine quantifiers should be able to bind variables (and bound variable pronouns in Natural Language), Generalized Quantifiers are not genuine quantifiers. What makes them appear to be binders is the effect of hidden lambda operators (the real binders) introduced at the level of Logical Form; cf. Heim & Kratzer (1998).[4]

This has two consequences: first, the quantifier must inform its scope (in the above framework: its restriction) about the variable it is going to bind; this is done by coindexation. Second, the quantifying DP itself can induce bound variable readings of pronouns. As in most other frameworks, this is achieved by coindexation, but unlike textbook semantics (cf. Heim & Kratzer 1998) we do not need additional mechanism like QR, whose psycholinguistic status is yet unclear (cf. section 4.4).

Composition proceeds along the same lines as in the examples above. The lexical entries of the determiner, the noun phrase and the thematic role are as follows[5]:

(29)   a. $[\![a_i]\!] = \lambda c \lambda p \exists x_i . c(p)$
       b. $[\![\text{boxer}_i]\!] = \lambda c \lambda p (\mathbf{boxer}(x_i) \wedge (c(p)))$
       c. $[\![\text{ag}_i]\!] = \lambda c \lambda p . c(p \wedge \mathbf{agent}(e, x_i))$

With the composition rule at hand, we can now derive the meaning of the entire DP:

(30)   a. $[\![\text{DP}_2]\!] = \lambda c [[\![a_i]\!] [[\![\text{boxer}_i]\!](c)]]$
            $= \lambda c [\lambda p \exists x_i [\lambda p (\mathbf{boxer}(x_i) \wedge c(p))](p)]$
            $= \lambda c \lambda p \exists x_i (\mathbf{boxer}(x_i) \wedge c(p))$
       b. $[\![\text{DP}_1]\!] = \lambda c [[\![\text{ag}_i]\!] [[\![\text{a boxer}_i]\!](c)]]$
            $= \lambda c [\lambda p [\lambda p \exists x_i (\mathbf{boxer}(x_i) \wedge c(p))](p \wedge \mathbf{agent}(e, x_i))]$
            $= \lambda c \lambda p \exists x_i (\mathbf{boxer}(x_i) \wedge c(p \wedge \mathbf{agent}(e, x_i)))$

This is exactly the meaning of the DP *a boxer* from (7) with the thematic role R instantiated as *agent* role. The example shows that our composition rule is flexible enough to cover DP internal composition up to composition at the sentence level. More examples will be dicussed in the next section.

Instead of the linear scope derivation in (30) we could also try to compute a meaning

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[4]On the other hand, the expression of quantity is not part of the semantics of genuine quantifiers, rather it normally goes into the restriction of a second order existential quantifier. For example, an expression like *five books* in our framework would not contain *five* as a Generalized Quantifier, but a second order property (an adjective) *five* that restricts (together with *books*) a syntactically empty determiner that is interpreted as second order existential quantifier. Thus, binding and the expression of quantification are different semantic issues that go together under the label "quantifier" but should not be confused under closer scrutiny; cf. Sternefeld (to appear).

[5]The reader should be warned that (29-a) does not generalize to other quantifiers; see section 4.3 below.

of DP_1 applying the rule for inverse scope. However, the following derivation shows that this would violate the *Variable Binding Constraint* from (27): x_i ends up unbound outside the scope of the existential quantifier.

(31) $[\![DP_2]\!] = \lambda c[\![boxer_i]\!][\![a_i]\!](c)]]$
     $= \lambda c[\lambda p(\mathbf{boxer}(x_i) \wedge [\lambda p(\exists x_i(c(p)))](p))]$
     $= \lambda c \lambda p(\mathbf{boxer}(x_i) \wedge \exists x_i(c(p)))$

This directly connects to a potential concern about the cross-linguistic validity of the proposed framework. An anonymous reviewer doubted whether the proposed compositional analysis can account for linearizations inside of DPs different from English or German DPs. We would like to briefly comment on DP internal composition in head-final languages like Japanese. Here, the semantic processor has to interpret structures [$_{DP}$ NP Det] and strings such as *boxer some* (see, e.g., Takahashi 2002). Note that exactly the same meaning is derived in this linearization as in the English example (7) if we apply the rule for inverse scope instead of the linear scope rule. At first sight, this may look like introducing a considerable degree of arbitrariness, ambiguity, and complexity into the system since for each incoming word the processor would have to check both scopings and therefore compute two representations. We would like to stress that the actual decision which composition rule is required is rather unproblematic in most cases because it is subject to an independently required well-formedness constraint on semantic derivations. The *Variable Binding* constraint repeated from (27) above rules out the assignment of inverse scope in head-initial DPs and of linear scope in head-final DPs:

(32) Variable Binding: If one linearization results in binding but the reverse linearization does not, only the former is grammatical.

Moreover, we would like to point out that no storage is required in this case, and complexity should thus be similar in head-initial and head-final DPs. The issue of restricted quantification inside DPs will be taken up again in section 4.3. There, the analysis will be refined by introducing separate continuation variables for the quantifier's restriction and its nuclear scope. However, we will start our discussion of the examples in (1) with the simplified representations introduced so far in order make the following analyses more easily accessible to the reader.

4 Sample derivations

4.1 Subject and transitive verb

We will now come back to the examples from the introduction and apply the just sketched incremental semantics to them. Our first example was:

(33) Eine Katze streichelte
     A   cat   petted

The DP *eine Katze* (*A cat*) is case ambiguous and therefore the sentence fragment allows for two interpretations: subject-verb vs. object-verb. A number of psycholinguistic studies of this sentence type has shown that the former interpretation is generally preferred over the latter. However, in (33) the syntactically preferred interpretation is ruled out on semantic or rather pragmatic grounds because cats cannot serve as agents of petting events. It has been shown that thematic processing leads to immediate reanalysis of the structure when the verb is encountered (e.g., Knoeferle et al. 2005). To model incremental interpretation in this type of example, we have to augment the apparatus above with encyclopedic knowledge. Simplifying a great deal, we assume that the knowledge base of the interpreter contains the facts that cats are not human but agents of petting events have to be. In general, world knowledge should be rather modeled in terms of default rules but for illustration purposes it is sufficient to model the required inferences via the following entailments.

(34) a. $\forall x(\textbf{cat}(x) \to \neg\textbf{human}(x))$
     b. $\forall e\forall x((\textbf{pet}(e) \land \text{agent}(e, x)) \to \textbf{human}(x))$

The initial interpretation of (33) will have the agent role assigned to *a cat*. The semantic processor will thus compute:

(35) $\lambda c\lambda p\exists x_i(\textbf{cat}(x_i) \land c(\exists e(\textbf{pet}(e) \land p \land \text{agent}(e, x_i))))$

This in combination with (20) and (34-a) gives rise to the inference that there is a petting event with a non-human agent. Combining this with encyclopedic knowledge (34-b) yields a contradiction. Thus, at this step in the incremental derivation interpretation is predicted to break down, and the sentence processor can be expected to resort to alternative parses of the sentence. In our example, there is a structural alternative with a fronted object DP yielding a well-formed semantic representation. Hence the parser is predicted to immediately revise the structure and shift to this structural alternative in accord to what has been reported in the psycholinguistic literature.

4.2 Double negation

(36) Kein Student war nicht
     No   student was not

The second example (36) involves the negative quantifier *no* and negation. This should lead to immediate processing difficulty relative to *ein Student war nicht* (*a student was not*) because the processor has to deal with double negation (cf. Clark & Chase 1972). To be able to model this relative difference, we need to compose the quantifier directly with

negation in the absence of the main verb. The auxiliary verb *war* (*was*) only contributes tense information (here *PAST*). The lexical entry for negation seems straightforward:

(37) $[\![\text{nicht}]\!] = \lambda c \lambda p. \neg c(p)$

The quantifier *kein Student* (*no student*) is represented in the format outlined in section 2.1.

(38) $[\![\text{kein Student}]\!] = \lambda c \lambda p \neg \exists x_i (\mathbf{student}(x_i) \wedge c(p \wedge \text{agent}(e, x_i)))$

The left to right derivation of the example is straightforward (ignoring tense for the moment; cf. section 4.5). The resulting representation contains double negation which should lead to immediate processing difficulty.

(39) $[\![\text{kein Student war nicht}]\!] = \lambda c[\![\text{kein Student}]\!][\![\text{nicht}]\!](c)]$
     $= \lambda c \lambda p \neg \exists x_i (\mathbf{student}(x_i) \wedge \neg c(p \wedge \text{agent}(e, x_i)))$

Note that instead of (39) we could also have used the rule for inverse scope. This way, we end up with (40)—the inverse scope reading.

(40) $\lambda c[\![\text{nicht}]\!][\![\text{kein Student}]\!](c)]$
     $= \lambda c \lambda p \neg \neg \exists x_i (\mathbf{student}(x_i) \wedge c(p \wedge \text{agent}(e, x_i)))$
     $= \lambda c \lambda p \exists x_i (\mathbf{student}(x_i) \wedge c(p \wedge \text{agent}(e, x_i)))$

To our knowledge, incremental effects of double negation in the absence of the verb have not been tested yet. We are currently conducting an eyetracking experiment during reading that investigates the time course of double negation effects in German sentences such as (36).

4.3 Adjacent DPs

The proposed theory allows us to compose two DPs before having encountered the verb. This is illustrated by the scope ambiguous German example repeated from (1-c).

(41) Dass keinen Studenten   jeder Professor   ...
      That no   student$_{object}$ each professor$_{subject}$ ...
      That each professor no student

We can employ the composition rules for inverse or linear scope, respectively. Let us start with the linear interpretation.

(42) $[\![\text{keinen}_i \text{ Studenten}_i \text{ [th]}_i > \text{jeder}_j \text{ Professor}_j \text{ [ag]}_j]\!]$
     $= \lambda c[\![\text{keinen}_i \text{ Studenten}_i \text{ [th]}_i]\!][\![\text{jeder}_j \text{ Professor}_j \text{ [ag]}_j]\!](c)]$
     $= \lambda c \lambda p \neg \exists x_i (\mathbf{student}(x_i) \wedge \forall x_j (\mathbf{professor}(x_j) \rightarrow c(p \wedge \text{agent}(e, x_j) \wedge \text{theme}(e, x_i))))$

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This is the intended result. The inverse interpretation is derived analogously:

(43) $[\![$keinen$_i$ Studenten$_i$ [th]$_i$ < jeder$_j$ Professor$_j$ [ag]$_j]\!]$

  $= \lambda c[\![$jeder$_j$ Professor$_j$ [ag]$_j]\!][[\![$keinen$_i$ Studenten$_i$ [th]$_i]\!](c)]]$

  $= \lambda c\lambda p\forall x_j(\mathbf{professor}(x_j) \rightarrow \neg\exists x_i(\mathbf{student}(x_i) \wedge c(p \wedge \text{theme}(e, x_i) \wedge \text{agent}(e, x_j))))$

At this point, we must further modify our analysis of quantifiers. As is well-known a quantifier like *every* has a restriction and a scope, but so far we are not able to properly account for the restriction. Usually quantifiers are assumed to have a tripartite structure so that the material immediately following the quantifier goes into its restriction, whereas the end of the DP signals that the following material goes into its scope. In the terminology of Barker (2002), quantifiers need two continuations, one for its restriction and one for its scope. This is a reasonable assumption that can be implemented immediately into the present format. For example, the quantifier *every$_i$* in first order logic is represented as:

(44) $\lambda c\lambda p\lambda c'\lambda p'(\forall x_i)(c(p) \rightarrow c'(p'))$

When applying this format to the following material, as in *every old . . .* , the adjective *old$_i$* ($[\![$old$_i]\!] = \lambda c\lambda p.\mathbf{old}(x_i) \wedge c(p)$) goes into the restriction,

(45) $\lambda c[[\![$every$_i]\!](\text{old}_i(c))] = \lambda c\lambda p\lambda c'\lambda p'(\forall x_i)((\mathbf{old}(x_i) \wedge c(p)) \rightarrow c'(p'))$

as does everything following *old*, until we, at some point, stop feeding the restriction, e.g. in the presence of material that cannot be part of the same DP. Having fully processed the restriction of the quantifier, c and p have to be eliminated as described in (20). The result now continues with $\lambda c'\lambda p'$ and has type $\langle t, t\rangle$ again, so we can proceed with the scope of the DP as usual.

As a consequence of this shift of types it will not be possible any more to directly process a chunk like:

(46) . . . (gave) a man every . . .

We rather have to store (*gave*) *a man*, then process the restriction of *every* and finally combine the result with the stored material. This is due to a type mismatch which arises from the new format of quantifiers; only after having processed the complete restriction, we arrive at the type $\langle t, t\rangle$ that is presupposed in our general rule (12). Note that the point at which the processor considers the restriction to be complete can vary depending on the context. The discussion of the PP attachment ambiguity in 4.6 will show that in the case of a two-referent context the processing of a definite description will lead to an expectation for more restricting information.

The present fragment only includes the first-order definable quantificational determiners *a/some*, *every* and *no*. In order to extend it to natural language quantifiers like *most*,

we have to include second order predicates into the system. The following lexical entry for *most* is the closest we can get in an otherwise first order framework (which ignores plural morphology and collective readings):

(47) $[\![\text{most}_i]\!] = \lambda c \lambda p \lambda c' \lambda p' (\exists Y \, MOST(Y, \lambda x_i.c(p)) \wedge \forall x_i (Y(x_i) \to c'(p')))$
     where $MOST(Y, X) = 1$ iff $Y' \subseteq X'$ and $\text{card}(Y') > \text{card}(X' \setminus Y')$
     with $Y' = \{y : Y(y) = 1\}$ and $X' = \{x : X(x) = 1\}$.

4.4   Permutation of DPs

As has frequently been observed in the literature, the local scope inversion in sentences with three (possibly adjacent) quantifying expressions, as in

(48)   Most professors sent a letter to every student

does not generate all six logical possibilities but only four of them; this not only holds in the present account which procedes from left to right but also in theories that adhere to syntactic structure and therefore procede from right to left. Whether or not all six possibilities are real is disputed (cf. Barker 2002, Sternefeld 2010). As far as our intuitions for (48) are concerned, it is, however, hardly controversial that the scoping *most>every>a* should be derivable, which it is not when proceding from left to right.

Of course one could resort to the assumption that, at the end of the day, syntactic structure must not be totally be ignored: in fact if we follow the usual bottom up analysis and the textbook semantics, the order could be derived by applying scope inversion at the bottom, before reaching the subject. On the other hand, we discussed above at the end of section 2.3 that some storing device is independently needed in order to deal with scope inversion. Perhaps, if storing could be iterated, the intended scope relations can be derived by (a) first processing *most professors sent*, (b) storing the result, (d) analysing *a letter* and again storing the result, (e), processing *every student* and (f) finally combining the result by emptying the storage, preferably in a last-in-first-out order.[6]

4.5   Tense mismatch

In this section we will consider tense mismatch in the absence of a lexical verb.

(49) Morgen   hatte ...
     Tomorrow had   ...

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[6]In any case, the procedure is diffent from quantifier raising QR: this should be clear from the fact that storing is needed indepently of QR. This result is particularly welcome, as representational parsimony makes a theory without QR more appealing than QR theories with their assumptions about covert syntax and an additional representational level of LF (but see Hackl, Koster-Hale & Varvoutis (2012) and the reply in Szabolcsi (2014) for a recent debate about the cognitive reality of QR).

This is a particularly interesting test case for incremental semantic interpretation because under standard assumptions, tense can only be interpreted after having encountered the complete VP determining lexical aspect/Aktionsart and grammatical aspect, relating the event time to the reference time. Nevertheless, we expect semantic processing to immediately break down when encountering the auxiliary. In two ERP studies, Baggio (2008) and Bott (2010, ch. 9) have found effects right at the verb in similar constructions involving tense mismatch.

We adopt the referential theory of tense and take *PAST* to introduce the presupposition that the reference time precedes the time of utterance (cf. McCawley 1971, Partee 1973, Webber 1988). In order to be able to deal with presupposed content, we adopt the theory of AnderBois, Brasoveanu & Henderson (2015) and assume a single representation which contains the asserted as well as the presupposed content. The difference between these two content types is how they are evaluated. While asserted or at-issue content makes a new proposal that has to be added to a common ground, i.e. the context set CS, presupposed content does not (and cannot be negated). Instead, it has to be checked against the existing common ground. Henceforth, we will write the subscript CS whenever a relation is presupposed, ie. has to be checked against the common ground and projects across negation.

From the perspective of this theory, our treatment of negation in section 4.2 was actually a simplification. As presupposed content cannot be negated, this must be implemented into the meaning of negation. We will ignore this detail and refer the reader to the definitions in AnderBois, Brasoveanu & Henderson (2015). Moreover, thematic relations are not asserted but presupposed, hence we should write $agent_{CS}(e, x)$ rather than $agent(e, x)$. Again, we will not adopt this convention, because we can understand $agent(e, x)$ in an already modalized manner: As all formulae are implicitly modalized (asserted material, i.e. formulae without the index CS, must be compatible with CS and presupposed material must follow from CS), we interpret $agent(e, x)$ as saying that the thematic relation of being the agent of e holds in all possible worlds of the context set.

Once we are able to express presupposed content, the semantic contribution of tense information is straightforward. *PAST* introduces the presupposition that the reference time t_{ref} is before the utterance time t_{now}. In our system this comes down to:

(50) $[\![PAST]\!] = \lambda c \lambda p . t_{ref} <_{CS} t_{now} \wedge c(p)$

To derive the mismatch incrementally, we need a lexical entry for *tomorrow*. Applying our standard format this is $[\![tomorrow]\!] = \lambda c \lambda p (t_{ref} \subseteq \mathbf{tomorrow}(t_{now})) \wedge c(p)$. The reference time is situated within the day following the day on which the utterance was made. From this, we can immediately derive a mismatch because the presupposition of PAST constrains the available time intervals to times in the past, hence any assertion that there is a reference time in the future is inconsistent with the context's presupposition.

(51) $[\![morgen \; hatte]\!] = \lambda c [\![tomorrow]\!] [[\![PAST]\!](c)]$

$$= \lambda c \lambda p(t_{ref} \subseteq \mathbf{tomorrow}(t_{now}) \wedge t_{ref} <_{CS} t_{now} \wedge c(p))$$

4.6 PP modifiers

Sentence (52-a) displays an attachment ambiguity which has received great attention in the psycho- and neurolinguistic literature on sentence processing.

(52) a. Put the apple on a towel...
   b. One-referent context: one apple on a towel; another towel without an apple
   c. Two-referent context: two apples, one on a towel, another apple not on a towel; a second towel without an apple

(52-a) can either be interpreted by attaching the prepositional phrase to a verbal projection, so that the empty towel may serve as goal of the put event; or it can be attached to the DP, so that the PP is interpreted as a locative modification of the apple (= the apple on a towel). Besides a number of experimental studies applying other techniques, eye-tracking studies in the visual world paradigm starting with Tanenhaus et al. (1995) have provided particularly strong evidence for immediate disambiguation of sentence (52-a) on the basis of visually presented contextual information. In the one-referent context (52-b) upon hearing the DP *the apple*, comprehenders strongly tend to interpret the PP as the goal of the required action resulting in looks to the goal "referent", ie. the empty towel. This preference has been explained by the fact the DP *the apple* is already sufficient to establish unique reference in this kind of context. The typical looking pattern is fundamentally different in the two-referent context (52-c). Here, in order to establish reference to a unique apple the processor can be expected to anticipate additional restriction further downstream the sentence. And in fact comprehenders seem to attach the PP immediately to the NP imposing further restriction as evidenced by looks to the apple located on the towel instead of looks to the empty towel.

In order to deal with this example, we need lexical entries for the definite article and the preposition *on*. In general, PPs can be used either as (a) prepositional objects, (b) adverbial modifiers, or (c) predicate modifiers inside DPs. The ambiguity observed above is one between (a) and (c). As for (a), we assume that the preposition works just like a thematic role [on] which is semantically selected by the verb. In case of (b) we assume the same analysis, except that the thematic role is not selected by the verb. In both cases the analysis precedes as above. It remains to account for (c), in which the PP elaborates the restriction of a preceding determiner.

In the above case, we assume a Russelian analysis of the definite description as a quantifier, with the twist that the uniqueness and existence is presupposed:

(53) $[\![\mathbf{the}_i]\!] = \lambda c \lambda p \lambda c' \lambda p' \exists x_i (\forall y (c_{CS}(p_{CS}) \leftrightarrow x_i = y) \wedge c'(p'))$

As a notational convention, we put the presupposition in curly brackets:

(54) $[\![\text{the}_i]\!] = \lambda c \lambda p \lambda c' \lambda p' \exists x_i (\{\forall y(c(p) \leftrightarrow x_i = y)\} \wedge c'(p'))$

Accordingly, *the apple* translates as:

(55) $[\![\text{the}_i \text{ apple}_i]\!] = \lambda c \lambda p \lambda c' \lambda p' \exists x_i (\{\forall y((c(\mathbf{apple}(x_i) \wedge p) \leftrightarrow x_i = y)\} \wedge c'(p'))$

A presupposition check against context (52-b) leads to a successful verification of the uniqueness presupposition of the definite article. This and the fact that verbs like *put* have a strong lexical bias for the prepositional object interpretation explains why the processor immediately closes off the restriction of *the$_i$* and treats *on a towel* as the prepositional object of the verb. We just give the resulting interpretation:

(56) $[\![\text{put the}_i \text{ apple}_i \text{ on a}_j \text{ towel}_j]\!] = \lambda c \lambda p \exists x_i (\{\forall y(\mathbf{apple}(x_i) \leftrightarrow x_i = y)\} \wedge$
  $\exists x_j(\mathbf{towel}(x_j) \wedge c(\exists e(\mathbf{put}(e) \wedge p \wedge \text{theme}(e, x_i) \wedge \text{goal}(e, x_j)))))$

In the DP attachment construal, the continuation of the restriction is further elaborated by *on*. Let us assume that *on* in this construction is a property of states; this will facilitate all subsequent calculations which can now parallel the calculations with events. Integrating the subject of the relational preposition already into the preposition, the format of *on* is this:

(57) $[\![\text{on}_i]\!] = \lambda c \lambda p(c(\exists s(\mathbf{on}(s, x_i) \wedge p)))$

As before, we can now calculate

(58) $[\![\text{the apple on}]\!] = \lambda c \lambda p \lambda c' \lambda p' \exists x_i (\{\forall y((c(\exists s(\mathbf{on}(s, x_i) \wedge \mathbf{apple}(x_i) \wedge p))) \leftrightarrow x_i = y)\} \wedge c'(p'))$

Next we have to integrate *a towel*. We assume that this is the theme of s, so that having completed the restriction of a_j we get:[7]

(59) $[\![a_j \text{ towel}_j [\text{th}_{s,j}]]\!] = \lambda c \lambda p \exists x_j(\mathbf{towel}(x_j) \wedge c(p \wedge \text{theme}(s, x_j)))$

Next, by applying (58) to (59) we get

(60) $[\![\text{the}_i \text{ apple}_i \text{ on}_i \text{ a}_j \text{ towel}_j [\text{th}_{s,j}]]\!] =$
  $\lambda c \lambda p \lambda c' \lambda p' \exists x_i (\{\forall y(([\lambda p \exists x_j(\mathbf{towel}(x_j) \wedge c(p \wedge \text{theme}(s, x_j)))](\exists s(\mathbf{on}(s, x_i) \wedge$
  $\mathbf{apple}(x_i) \wedge p))) \leftrightarrow x_i = y)\} \wedge c'(p')) =$
  $\lambda c \lambda p \lambda c' \lambda p' \exists x_i (\{\forall y(\exists x_j(\mathbf{towel}(x_j) \wedge c(\exists s(\mathbf{on}(s, x_i) \wedge \mathbf{apple}(x_i) \wedge p) \wedge$
  $\text{theme}(s, x_j)))) \leftrightarrow x_i = y)\} \wedge c'(p'))$

---

[7]Another possibility would be not to complete the restriction of *a towel* but that of *the apple on*. We could then apply *a towel* to *the apple on*, so that *the apple* goes into the restriction of the embedded quantifier. This yields an alternative reading called "inversed linking" in the literature. The inversed linking reading can be illustrated by examples such as *the apple in every basket*.

We then have to close the restriction of *the*$_i$ by (20) and add the thematic role of *put*, say *theme* again; the result is shown in (61):

(61) $[\![\text{the}_i \text{ apple}_i \text{ on}_i \text{ a}_j \text{ towel}_j \text{ } [\text{th}_{s,j}][\text{th}_{e,i}]]\!] =$
$\lambda c \lambda p \exists x_i(\{\forall y(\exists x_j(\textbf{towel}(x_j) \wedge \exists s(\textbf{on}(s, x_i) \wedge \textbf{apple}(x_i) \wedge \text{theme}(s, x_j))) \leftrightarrow x_i = y)\} \wedge c(p \wedge \text{theme}(e, x_i)))$

This says that there is exactly one x_i and at least one x_j such that x_j is a towel and x_i is an apple such that x_i is on x_j. This presupposition is met in the two-referent context (52-c) because there is only a single apple located on a towel.

The discussion of example (52-a) shows that the continuation variables of a determiner's restrictor argument must be assumed to be closed off by (20) as soon as possible. In the one-referent context this led to a directional reading because the DP *the apple* could be immediately closed off for further restriction which immediately ruled out DP internal modification. In the two-referent context the resulting interpretation was different because the presupposition failure for the string *put the apple* prevented the processor from closing off the continuation variables of the determiner's restrictor argument.

5 The time course of aspectual interpretation

5.1 Case study

Bott & Gattnar (2015) investigated the timing of aspectual mismatch effects of transitive *achievement* verbs (e.g., *win*, *spot*, *reach*—cf. Vendler (1957)) modified by *for*-adverbials. The following German and Russian (unacceptable) sample sentences illustrate this kind of aspectual mismatch:

(62) a. Die Boxerin gewann den Kampf ganze drei Stunden und . . .
The female boxer won the fight whole three hours and . . .
The boxer won the fight for three hours and . . .
b. Znamenitaja i opytnaja boksersa vyigrala turnir celyx
Famous and experiences female boxer won$_{perfective}$ tournament whole
tri casa i . . .
three hours and . . .
The famous and experienced boxer won the fight for three hours and . . .

A crucial difference between German and Russian is that Russian has grammatical aspect and speakers always have to choose between a perfective or an imperfective verb form. Perfective aspect roughly corresponds to a wholistic, outside perspective of the reported event, while imperfective aspect encodes an internal perspective (Comrie 1976). We will come to a more precise characterization of these forms below. In German, though, this is different because there is only one verb form suited to encode any particular perspective

on the event, for instance, whether it is complete or not. Nevertheless, in both languages achievement verbs denote punctual events that involve a change of state, for instance, becoming the winner. Moreover, both German and Russian are languages with a rather free word order.

(63) a. Ganze drei Stunden gewann die Boxerin   den Kampf und . . .
        For   three hours   won   the female boxer the fight   and . . .
     b. Celyx tri   casa vyigrala   znamenitaja i opytnaja boxersa
        For   three hours won$_{perfective}$ the famous and experienced female boxer
        turnir   i   . . .
        the tournament and . . .

In Bott & Gattnar's (2015) study, German and Russian participants' eye gaze was measured while reading the two construction types. In each construction, the aspectual mismatch condition was compared to a control condition which had an *ago*-adverbial (*vor drei Stunden* and *tri casa nazad*, respectively) instead of a *for*-adverbial. The study investigated whether the time course of mismatch detection in the two constructions is the same across aspect and non-aspect languages. Based on semantic literature on aspectual composition and work in mereological semantics, Bott and Gattnar hypothesized that, in the absence of grammatical aspect, it only becomes evident that the processor is dealing with an achievement after having processed the German verb together with all its arguments. For an aspect language like Russian, by contrast, they predicted that the time course should be different showing maximally incremental effects. Their predictions were based on the well-known fact that in aspect languages the aspect marking of the verb ultimately determines the semantic properties of the arguments, whereas in non-aspect languages the opposite holds. For instance, whether a given Russian noun is count or mass depends on the aspect marking of the verb. However, whether a German verb phrase encodes a telic or an atelic event depends on whether its arguments are count or mass. Below, we will apply the proposed theory to this test case and derive these predictions more formally in left-to-right derivations.

This cross-linguistic variation was clearly reflected in the eyetracking data. We only report one eyetracking measure here, the regression-path durations, but the other measures were fully consistent with these data. This eyetracking measure represents the sum of all fixations starting with the first fixation in a region and ending with the first forward saccade past that region. Figure 1 shows the mean regression path durations for the two constructions in both languages.

German and Russian readers differed in how early they detected the mismatch between achievement verbs and *for*-adverbials. Russian readers showed aspectual mismatch effects immediately at the critical region (the verb in the ADV-V order and the adverbial in the SVO-ADV order). Thus an incremental effect of adverbial modification was observed irrespective of whether the verb preceded or followed its nominal arguments. By contrast, German readers behaved rather differently. Aspectual mismatch effects were

(a) SVO-Adv order, Russian   (b) Adv-V order, Russian

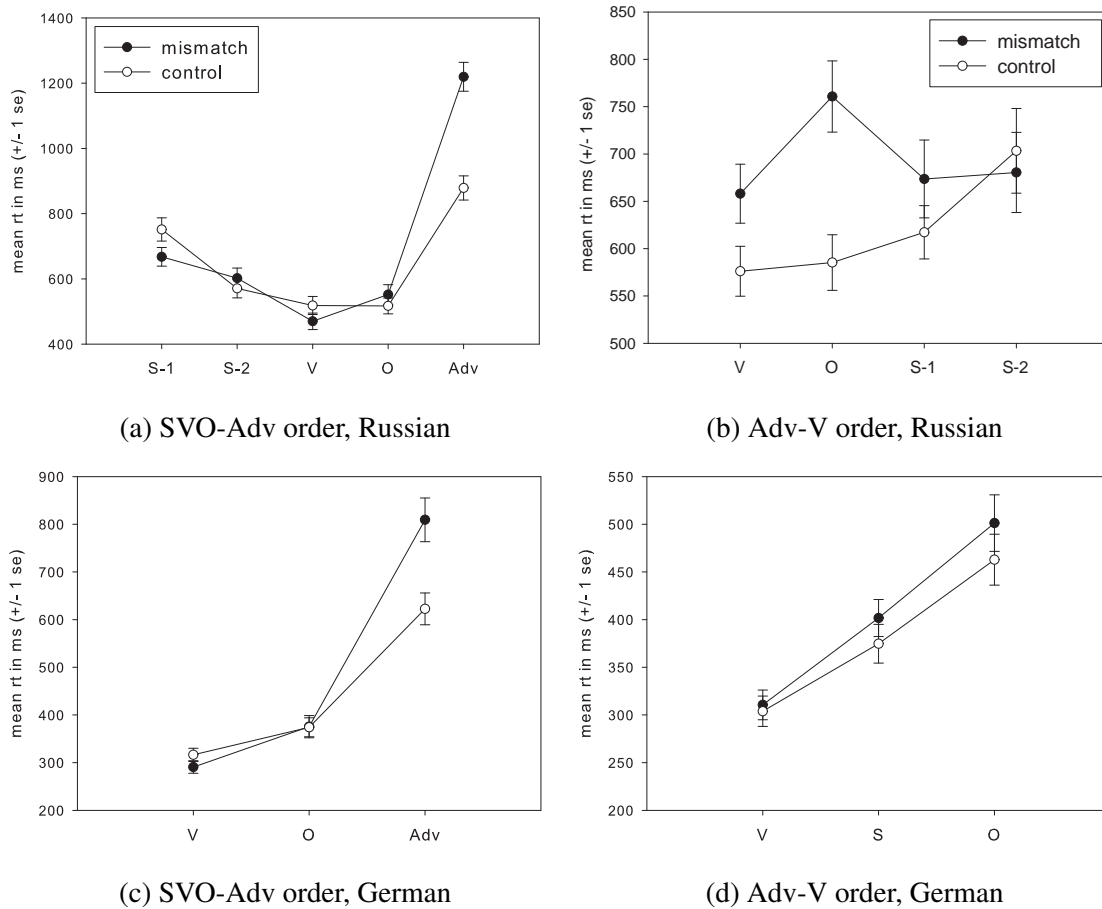(c) SVO-Adv order, German   (d) Adv-V order, German

Figure 1: Mean regression path durations of Russian and German mismatch and control conditions in the two word orders (conditions in Panels (a) and (c) correspond to examples (56-a) and (56-b) and Panels (b) and (d) correspond to examples (57-a) and (57-b)). In the SVO-ADV word order, mismatch detection had the same timing in both languages (Panels (a) and (c)). A cross-linguistic processing difference between Russian and German was observed in the ADV-V order: Russian readers showed an immediate mismatch effect at the verb (Panel (b)), German readers showed a mismatch effect only after they had encountered the complete predication (Panel (d)). Error bars represent the standard errors of the mean computed on the basis of the analyses by participants. Abbreviations: Adv = adverbial, V = verb, S-1 = first region of the subject (adjective and adjective), S-2 = second region of the subject (noun), S = subject, O = object. Data from Bott & Gattnar (2015).

delayed until the minimal sentence was complete, that is until the obligatorily transitive achievement verbs had received their subject and direct object arguments, respectively. We cannot go into further details but refer the interested reader to Bott & Gattnar (2015).

Interesting for the purposes of the present paper are two issues: First, we would like to be able to formally derive the incremental mismatch effect in Russian. Secondly, we would like to show that an aspectual mismatch in German can indeed only be derived for the complete verb argument structure. To do so, we need to adopt insights from mereological semantics (Link 1983, Bach 1986, Krifka 1989, Krifka 1992, Krifka 1998, Filip 2000) and integrate lexical and grammatical aspect into our formal system. We will do so in the next subsection before we return to the German and Russian examples in (62) and (63).

5.2 Lexical and grammatical aspect

Mereological semantics explains the intricate interdependency between lexical aspectual classes, the semantic contribution of a verb's nominal arguments and grammatical aspect. These factors are brought together by a close linkage between the semantics of events, times and objects, and, in particular, whether a verbal or nominal predicate has cumulative or quantized reference, two properties we will introduce below in (65). According to this view, both domains—the domain of events and the object domain—include plurals and mass entities. All entities are assumed to stand in the parthood relation usually taken as primitive (Link 1983).

The set A illustrates a part-whole structure: $A = \{a, b, c, a \oplus b, a \oplus c, b \oplus c, a \oplus b \oplus c\}$. The ontological domain can consist of algebraic structures over objects, events or time intervals. If a, b and c denote objects and in particular represent specific amounts of water, A exemplifies the semantics of the mass noun *water*. Whenever two entities are in the denotation of *water*, their sum is, too. The same holds for events. If a, b and c are jogging events by John, then any of their sums is in the denotation of *John is jogging*, too. Similarly, time intervals can form a mereology.

We will follow Krifka (1998) and take *sum* as primitive and define *(proper) parthood* from it (cf. Krifka 1998, p. 198).

(64) $P = \langle U_P, \oplus_P, \leq_P, <_P, \otimes_P \rangle$ is a *part structure* (mereology) iff

    a. U_P is a set of entities (either objects/mass, eventualities (states, processes and events) or time intervals)

    b. $\oplus_P$, the *sum operation* is a function from $U_P \times U_P$ to U_P that is idempotent, commutative, and associative:
$\forall x, y, z \in U_P(x \oplus_P x = x \wedge x \oplus_P y = y \oplus_P x \wedge x \oplus_P (y \oplus_P z) = (x \oplus_P y) \oplus_P z)$

    c. $\leq_P$, the *part relation*, defined as: $\forall x, y \in U_P(x \leq y \leftrightarrow x \oplus_P y = y)$

    d. $<_P$, the *proper part relation*, defined as: $\forall x, y \in U_P(x < y \leftrightarrow x \leq_P y \wedge x \neq y)$

    e. $\otimes_P$, the *overlap relation*, defined as: $\forall x, y \in U_P(x \otimes_P y \leftrightarrow \exists z \in U_P(z \leq_P x \wedge z \leq_P y))$

    f.   Remainder principle: $\forall x, y \in U_P(x <_P y \rightarrow \exists! z(\neg(z \otimes_P x) \wedge x \oplus_P z = y))$

On the basis of the notion of a part structure, various second order predicates (65) can be defined: homogenous predicates with *cumulative* (CUM$_P$) and *divisive* (*DIV$_P$*) reference as opposed to *quantized* (*QUA$_P$*) predicates (definitions adopted from Krifka 1992, Krifka 1998). In the domain of events these predicates allow us to distinguish between telic event types, ie., events that involve a resultant state (Vendler's achievements and accomplishments) on the one hand, and atelic event types such as activities and stative eventualities on the other. While the former are quantized, the latter are homogeneous.

(65) a. $\forall X \subseteq U_P(CUM_P(X) \leftrightarrow \exists x, y(X(x) \wedge X(y) \wedge \neg x = y) \wedge \forall x, y(X(x) \wedge X(y) \rightarrow X(x \oplus_P y)))$
(a predicate is cumulative iff the predicate applies to at least two distinct entities and, whenever it holds of two elements, it also holds of their sum)

b. $\forall X \subseteq U_P(DIV_P(X) \leftrightarrow \forall x, y(X(x) \wedge y <_P x \rightarrow X(y)))$
(a predicate is divisive iff, whenever it holds of something, it also holds of its (proper) parts)

c. $\forall X \subseteq U_P(QUA_P(X) \leftrightarrow \forall x, y(X(x) \wedge X(y) \rightarrow \neg y <_P x))$
(a predicate is quantized iff, whenever it holds of something, it doesn't hold of any of its parts)

The mereological framework allows us to capture direct structural analogies and interactions between the denotations of verbal and nominal predicates. Bare mass and bare plural nominal predicates pattern with state (e.g. *be sad*) and process (e.g. *jog*) predicates, ie. they are cumulative and divisive (*homogeneous* ($HOM_P := \forall X[HOM_P(X) \leftrightarrow DIV_P(X) \wedge CUM_P(X)]$) for short). By contrast, count nominal predicates pattern with accomplishments (e.g. *build a house*) and achievements (e.g. *reach the top*) in so far as they are quantized/telic. These second order properties can also be used to capture the semantic contribution of durative adverbials of the kind *for three hours*. For our purposes, it suffices to assume that they take an event predicate as their argument and constrain their event time $\tau(e)$ to the value specified in the measure phrase, for instance *three hours*. Furthermore, they presuppose that the event predication P is divisive or, in other words, has the subinterval property (Bennett & Partee 1972).[8] That the latter is a presupposition becomes clear by looking at its projection behavior illustrated in (66):

(66) a. It is not true that John jogged for three hours.
b. Asserted: It is not the case that the run-time of John's jogging activity was three hours.

---

[8] See Moltmann (1991), Link (1991), Champollion (2010) and Landman & Rothstein (2010) for further amendments that have been proposed. Strictly speaking, the subinterval property should only hold of parts of a homogeneous predicate P with parts that are still coarse-grained enough to count as minimal situations for P or, to put it differently, that are of relevant size. Not every part of a waltzing event is itself a waltzing, for instance. The contribution of a *for*-adverbial stated here is thus oversimplified but will suffice for our purposes.

c. Presupposed: Whatever the run time of John's jogging activity was, he jogged throughout each relevant part of this time interval.

The presupposition is responsible for the fact that *for*-adverbials are generally bad with quantized event predicates, which by definition are incompatible with divisive event structures. We assume the semantics of *for*-adverbials in (67):

(67) $[\![\text{for x time}]\!] = \lambda c \lambda p (DIV_{CS}(\lambda e'(c(p \wedge e = e'))) \wedge c(p \wedge \ \tau(e) = \text{x time}))$

A brief remark on the exact form of the presupposition term is in order here to motivate why we make use of λ abstraction. The property of divisibility—as well as cumulativity and being quantized—is defined for event predicates, ie. sets of events. In our theory, following Champollion (2015), the event variable is existentially bound right from the start of the derivation already in the lexical entry of the verb. We therefore have to reconstruct an event predicate from the existentially bound event token. This is exactly what the abstraction achieves. This is illustrated in (68) where we focus on the crucial part $\lambda c \lambda p (\lambda e'(c(p \wedge e = e')))$ and apply it to the general representation of a lexical verb:

(68) $\lambda c [\lambda p'(\lambda e'(\lambda p''(c(\exists e(\mathbf{verb}(e) \wedge p'')))) (p' \wedge e = e'))]$
$= \lambda c [\lambda p'(\lambda e'(c(\exists e(\mathbf{verb}(e) \wedge p' \wedge e = e'))))]$
$= \lambda c \lambda p (\lambda e'(c(\mathbf{verb}(e') \wedge p)))$

To derive the aspectual mismatch between *for*-adverbials and achievement predicates in German, it is crucial to be explicit about the aspectual semantic contribution of the nominal arguments. In the mereological tradition, following Krifka, this is achieved by reflecting upon thematic roles as linking relations between the nominal arguments and the event type expressed by the VP. What preconditions must be fulfilled for the predication denoted by a complete VP to be quantized? Relevant for our current purposes is theorem 11 by Krifka (1992, p. 41), where P is a predicate of objects, V an event predicate (a VP-denotation) and R a thematic role relating events to objects. A thematic relation exhibits *uniqueness to objects* (*UNI-O*) iff for any event there is a unique object participating in that event. Similarly, a thematic relation displays *uniqueness to events* (*UNI-E*) iff every object is mapped onto a unique event. Finally, *mapping to objects* (*MAP-O*) holds iff any part of an event can be uniquely mapped onto a part of the object participating in it.

(69) $\forall P, R(QUA(P) \wedge \textit{UNI-O}(R) \wedge \textit{MAP-O}(R) \wedge \textit{UNI-E}(R) \rightarrow QUA(\lambda e \exists x (P(x) \wedge R(e, x))))$

An important consequence of this theorem is that if the context constrains the event predicate to be non-quantized (as for instance if the event predicate appears in the scope of a *for*-adverbial), then the antecedent of the conditional must be false. However, in order to check whether it is false, we first need to know about the semantic properties of the object predicate P (and the thematic relation R) because otherwise it is im-

possible to decide whether $QUA(P)$ is true. For instance, the semantic properties of the event participant in the case of *mow the lawn* have to be known in order to show that $QUA(\lambda e \exists x(\text{mow}(e) \wedge \text{theme}(e, x)))$ because QUA(the lawn) and *UNI-O*, *UNI-E* and *MAP-O* of the particular theme relation involved in the example[9]. As a consequence, lexical aspect is in fact not a property of verbs but of complete verb-argument structures. This receives empirical support by the contrast between (70-a) and (70-b) where *the fight* is quantized but *one fight after another* is not.

(70) a. #The whole morning, the boxer won the fight.
　　　 b. The whole morning, the boxer won one fight after the other.

Other examples discussed in Krifka (1992) include the accomplishment (71-a) and activity (71-b) verb phrases. The patient role of the verb of creation *write* in combination with the quantized object *the letter* fulfills the antecedent of the conditional in (69), and, in fact, the VP denotation turns out to be quantized. Evidence for this fact comes from adverbial modification: it is good with *in-* but bad with *for*-adverbials.[10] By contrast, (71-b) is cumulative and therefore non-quantized (partly) because *letters* has cumulative reference and the VP is thus subject to another theorem (Theorem (T6) in Krifka 1992, p. 40).

(71) a. write the letter (in an hour/?for an hour)
　　　 b. write letters (for an hour/*in an hour)

The property of being quantized is not only crucial to distinguish lexical aspectual classes but is central for grammatical aspect, too, because it allows us to characterize the notion of perfectivity. Again, following Krifka (1992), we will assume that - whatever perfectivity may exactly be - perfective aspect can only be assigned to verbal predicates that are quantized, or rather, predicates that are telic. This entailment immediately explains why grammatical aspect disambiguates the interpretation of nominals which are ambiguous between a bounded and an unbounded interpretation, cf. the Czech example (72).

(72) a. Pil　　　　　　　　　víno.
　　　　　 drink-imperfective-past-sg wine-sg-acc.
　　　　　 '∅ was drinking wine.'
　　　 b. Vypil　　　　　　　　víno.
　　　　　 drink-perfective-past-sg wine-sg-acc.
　　　　　 '∅ drank up the wine.'

---

[9]The achievements used in the case study are somewhat pathological cases because both the events and the involved objects denote singleton sets. Nevertheless, they conform with $QUA(P)$, $UNI\text{-}O(R)$, $MAP\text{-}O(R)$ and $UNI\text{-}E(R)$, too.

[10]It is perhaps possible to coerce *the letter* from a quantized object into an object with cumulative reference, ie. a partial letter. We therefore labeled the example with a question mark (see Bott & Hamm (2014) for further discussion and on- and offline data concerning the processing and interpretation of English and German accomplishments modified by *for*).

We have to add that a number of proposals exist for the semantics of perfective aspect. According to Hana Filip, for instance, perfectivization of an event predicate involves the application of an operator MAX_E (Filip & Rothstein 2005, p. 92):

(73) The *maximization operator MAX_E* is a monadic operator, such that $MAX_E(P) \subset P$. It maps sets of events, (partially) ordered by an ordering criterion for objects on a scale, onto sets of maximal events.

We would like to point out that the maximization of a predicate $MAX_E(P)$ entails that P is quantized $QUA(P)$. Again following Krifka (1992) we will assume that whatever perfectivity *PERFECTIVE*(P) may exactly be, it is uncontroversial that $\forall P[\textit{PERFECTIVE}(P) \rightarrow QUA(P)]$. We will assume that the quantization constraint is a presupposition, too.

As for the assertion of perfective aspect, we follow Paslawska & von Stechow (2003) and model the default interpretation of the perfective in interval semantics. Paslawska and von Stechow employ the relation *includes* of Klein (1994), that is, the event time $\tau(e)$ is temporally included in the reference time t_{ref}. (74) is the resulting lexical entry for perfective aspect in our continuation format.

(74) $[\![\textit{PERFECTIVE}]\!] = \lambda c \lambda p (QUA_{CS}(\lambda e'(c(p \wedge e = e'))) \wedge c(p \wedge \tau(e) \subseteq_T t_{ref}))$

5.3 Modeling the time course of aspectual mismatch detection in German and Russian

We are now ready to apply our system to the examples of the case study from above and start with the German examples in (75-a) and (75-b) repeated from above before moving on to the Russian examples. (75-a) involves an aspectual mismatch between the fronted durative adverbial and the achievement predicate. (75-b) served as control condition. (75-c) is the lexical entry for *vor zwei Stunden* (*two hours ago*).

(75) a. #Ganze zwei Stunden gewann   der Boxer den Kampf
        Whole two hours   win-PAST the boxer the fight
        'For two hours won the boxer the fight'
     b. Vor zwei Stunden gewann   der Boxer den Kampf
        Ago two hours   win-PAST the boxer the fight
        'Two hours ago won the boxer the fight'
     c. $[\![\text{two hours ago}]\!] = \lambda c \lambda p (t_{ref} = t_{now} - 2h \wedge c(p))$

Let us consider the incremental derivation of the control condition first. Leaving aside the presupposition of the definite article (cf. section 4.6), for simplicity we will treat definite descriptions like proper names and assume that *der Boxer* (*the boxer*) and *der Kampf* (*the fight*) are interpreted as constants. Alternatively, we could have chosen the representation

of definite descriptions introduced in section 4.6, but this would unnecessarily complicate the derivations.

(76) a. $\lambda c[[\![\text{two hours ago}]\!][[\![\text{win}]\!](c)]]$
$= \lambda c \lambda p(t_{ref} = t_{now} - 2h \wedge c(\exists e(\textbf{win}(e) \wedge p)))$

   b. $\lambda c[[\![\text{two hours ago win}]\!][[\![\text{PAST}]\!](c)]]$
$= \lambda c \lambda p(t_{ref} <_{CS} t_{now} \wedge t_{ref} = t_{now} - 2h \wedge c(\exists e(\textbf{win}(e) \wedge p)))$

   c. $\lambda c[[\![\text{two hours ago win PAST}]\!][[\![\text{the boxer}]\!](c)]]$
$= \lambda c \lambda p(t_{ref} <_{CS} t_{now} \wedge t_{ref} = t_{now} - 2h \wedge c(\exists e(\textbf{win}(e) \wedge p \wedge \text{agent}(e, \textbf{the boxer}))))$

   d. $\lambda c[[\![\text{two hours ago win PAST the boxer}]\!][[\![\textbf{the fight}]\!](c)]]$
$= \lambda c \lambda p(t_{ref} <_{CS} t_{now} \wedge t_{ref} = t_{now} - 2h \wedge c(\exists e(\textbf{win}(e) \wedge p \wedge \text{theme}(e, \textbf{the fight}) \wedge \text{agent}(e, \textbf{the boxer}))))$

   e. $\lambda c[[\![\text{two hours ago win PAST the boxer the fight}]\!][[\![\text{includes}]\!](c)]]$
$= \lambda c \lambda p(t_{ref} <_{CS} t_{now} \wedge t_{ref} = t_{now} - 2h \wedge c(\exists e(\textbf{win}(e) \wedge p \wedge \tau(e) \subseteq t_{ref} \wedge \text{theme}(e, \textbf{the fight}) \wedge \text{agent}(e, \textbf{the boxer}))))$

Note that step (76-e) is not triggered by any lexical material in the sentence. We assume that speakers of German, even though they have no grammatical means to express aspect, nevertheless need to decide on an aspectual interpretation in order to relate the event time $\tau(e)$ to the reference time t_{ref}. For an achievement, ie. a punctual change of state, the only possible relation is inclusion: $[\![\text{includes}]\!] = \lambda c \lambda p(c(p \wedge \tau(e) \subseteq t_{Ref}))$ (cf. (76-e)). The resulting representation is exactly as it should be: the sentence is true iff there was an event of the boxer winning the fight and this event happened two hours before the utterance was made. The derivation shows that any piece of information could be integrated in the incremental order of appearance.

Next, we will consider aspectual mismatch in German achievement sentences with topicalized *for*-adverbials. Again, we provide an incremental derivation in the linear order in which the sentence is encountered. In addition, we assume that presuppositions are checked in each processing step. A presupposition check consists in the application of the trivial continuation $(\lambda p.p)(\top)$ (cf. section 2.1) and then checking against the context set CS whether the resulting proposition is contextually supported or can be accommodated.

(77) a. $\lambda c[[\![\text{for two hours}]\!][[\![\text{win}]\!](c)]]$
$= \lambda c[\lambda c \lambda p(DIV_{CS}(\lambda e'(c(p \wedge e = e'))) \wedge c(p \wedge \tau(e) = \textbf{2 hours}))(\lambda c \lambda p(c(\exists e(\textbf{win}(e) \wedge p))))(c)]$
$= \lambda c \lambda p(DIV_{CS}(\lambda e'(c(\textbf{win}(e') \wedge p))) \wedge c(\exists e(\textbf{win}(e) \wedge p)))$

   b. check: $DIV_{CS}(\lambda e'(\textbf{win}(e')))$
$\triangleright$ divisible win events

   c. $\lambda c[(77\text{-a})[[\![\text{PAST}]\!](c)]]$
$= \lambda c \lambda p(DIV_{CS}(\lambda e'(t_{ref} <_{CS} t_{now} \wedge c(\textbf{win}(e') \wedge p))) \wedge t_{ref} <_{CS} t_{now} \wedge c(\exists e(\textbf{win}(e) \wedge p)))$

d. check: $DIV_{CS}(\lambda e'(t_{ref} <_{CS} t_{now} \wedge \mathbf{win}(e')))$
   ▷ divisible win events in the past

e. $\lambda c[(77\text{-}c)[[\text{the boxer}]](c)]]$
   $= \lambda c\lambda p(DIV_{CS}(\lambda e'(t_{ref} <_{CS} t_{now} \wedge c(\mathbf{win}(e') \wedge p \wedge \text{agent}(e', \mathbf{the\ boxer}))))) \wedge$
   $t_{ref} <_{CS} t_{now} \wedge c(\exists e(\mathbf{win}(e) \wedge p \wedge \text{agent}(e, \mathbf{the\ boxer})))$

f. check: $DIV_{CS}(\lambda e'(t_{ref} <_{CS} t_{now} \wedge \mathbf{win}(e')\text{agent}(e, \mathbf{the\ boxer})))$
   ▷ divisible win events by the boxer in the past

g. $\lambda c[(77\text{-}e)[[\text{the fight}]](c)]]$
   $= \lambda c\lambda p(DIV_{CS}(\lambda e'(t_{ref} <_{CS} t_{now} \wedge c(\mathbf{win}(e') \wedge p \wedge \text{theme}(e', \mathbf{the\ fight}) \wedge$
   $\text{agent}(e', \mathbf{the\ boxer})))) \wedge t_{ref} \quad <_{CS} \quad t_{now} \wedge c(\exists e(\mathbf{win}(e) \wedge p \wedge$
   $\text{theme}(e, \mathbf{the\ fight}) \wedge \text{agent}(e, \mathbf{the\ boxer})))$

h. check: $DIV_{CS}(\lambda e'(t_{ref} \quad <_{CS} \quad t_{now} \wedge \mathbf{win}(e') \wedge \text{theme}(e', \mathbf{the\ fight}) \wedge$
   $\text{agent}(e', \mathbf{the\ boxer})))$

Only after both nominal arguments have been encountered, the presupposition can be evaluated. At this point, it becomes clear that it is incompatible with the information provided in the sentence. By Krifka's theorem (69), we can derive $QUA(\phi)$, and since by the definition of $QUA \ \forall P(QUA(P) \rightarrow \neg DIV(P))$, we get $\neg DIV(P)$, which contradicts the presupposition $DIV_{CS}(\phi)$. Hence, on our account, mismatch detection is only possible after both thematic roles are saturated with quantized nominal arguments. This corresponds to the time-course of aspectual mismatch detection reported in Bott & Gattnar (2015).

The crucial difference between the Russian and the German examples is that, in addition to what we just have outlined for German, Russian verbs are marked for grammatical aspect. Using the lexical information in (74) we would like to derive a local mismatch effect between a durative adverbial and perfective aspect along the following lines:

(78) $[[\text{for x time}]]([[\text{perfective}]]) \approx \lambda c\lambda p(DIV_{CS}(\lambda e'(c(p \wedge e = e'))) \wedge QUA_{CS}(\lambda e'(c(p \wedge e = e'))) \wedge c(p \wedge \tau(e) \subseteq t_{ref} \wedge \tau(e) = \mathbf{x\ time})))$

Let $\phi = \lambda e'(c(p \wedge e = e')$. This gives us the presupposition $DIV_{CS}(\phi) \wedge QUA_{CS}(\phi)$ which (as long as ϕ does not denote a singleton event or the empty set) expresses a plain contradiction. Hence, if the incremental analysis outputs (78), the aspectual mismatch should become obvious right at the morpheme marking perfective aspect—in line with what the eyetracking data suggest.

Unfortunately, this is not quite the result of the present system. Instead, applying the compositional rules, we either end up with perfective aspect taking scope over the durative adverbial or vice versa, resulting in one presupposition embedding the other:

(79) a. $[[\text{for x time}]]([[\text{perfective}]]) = \lambda c\lambda p(DIV_{CS}(\lambda e'(QUA_{CS}(\lambda e''(c(p \wedge e'' = e))) \wedge e' = e)) \wedge \ldots)$

b. $[[\text{perfective}]]([[\text{for x time}]]) = \lambda c\lambda p(QUA_{CS}(\lambda e'(DIV_{CS}(\lambda e''(c(p \wedge e'' = e))) \wedge e' = e)) \wedge \ldots)$

These formulae do not make any sense; in particular, the second occurrence of the variable e (in $e' = e$) is free and can never be bound irrespective of what material comes in later. Clearly, such a representation must be ruled out. Rather, we would like to calculate presuppositions by strictly separating the asserted from the presupposed content and update the two separately from each other.

In a previous version of this paper we achieved this by using two different continuation variables c_a, p_a for the asserted content and c_p, p_p for the presupposed content in tandem with a more complicated compositional rule. However, we later found out that the problem is much more general. For example, in a sentence with two presupposition triggers like *John too is smoking again*, compositional analysis would allow two scopal possibilities for the triggers, but in neither case do we get all the desired presuppositions: If *too* is in the scope of *again*, we miss the presupposition that someone else is smoking now, and if *again* is in the scope of *too*, we miss the presupposition that John has been smoking before (cf. Zimmermann & Sternefeld 2013, p. 277). Our hope is that a solution to this problem, which calls for a scope independent analysis of multiple presupposition triggers, would also carry over to the compositionality problem we faced above. At present, however, we are unaware of a proper solution.

6   Conclusions

The present article proposed a Neo-Davidsonian event semantics and spelled out left to right semantic analyses for a number of phenomena ranging from thematic processing over relative scope to aspectual interpretation and the interpretation of adverbial modification. For the most part, we were able to derive surface compositional analyses satisfying three principles for text comprehension put forward in Vermeulen (1994) for propositional logic and Brasoveanu & Dotlacil (2015) for a recent extension to first-order predicate logic:

(80) a. **Compositionality**: the meaning of a sentence or text is determined by the meaning of its parts and the way they are combined.
      b. **Incrementality**: every new piece of information is immediately integrated into the semantic representation of the sentence or text processed so far.
      c. **Break-in**: every segment of a sentence or text should be interpretable.

It is important to emphasize once more that the proposed incremental semantics is by itself not intended to be a processing theory. Rather, we hope that it can be used by psycho- and neurolinguists to spell out compositional steps in processing theories. The proposed model is therefore compatible with very different theories of sentence interpretation, ranging from serial, modular accounts (e.g. Frazier 1987) to parallel, interactive processing theories (e.g. McRae, Spivey-Knowlton & Tanenhaus 1998). Our aim was to spell out the incremental compositional construction of meaning within sentences, much

more fine grained than the propositional representations in text comprehension theories, as for instance Kintsch's (1988) construction-integration model.

Equipped with a better understanding of the incrementally evolving sentence interpretation, we can address open empirical questions within experimental semantics. Bott & Schlotterbeck (2015), for instance, presented evidence from eyetracking and self-paced reading that scope interpretation may not be computed fully incrementally but seems to depend on rather large increments, namely complete sentences. They investigated scope processing in doubly quantified sentences in which the first quantifier had to undergo scope reconstruction for a possessive pronoun to be bound, illustrated in (81).

(81) Jeden seiner Student   hat genau ein Professor   gelobt.
      Each of his pupils$_{object}$ has exactly one professor$_{subject}$ praised.
      Exactly one professor has praised each of his pupils.

Reading time effects of scope inversion were delayed until the end of the sentence. However, scope reconstruction may just be a special case and it has to be seen whether non-incremental interpretation is a property of scope interpretation in general (see, e.g. Aoshima, Yoshida & Phillips 2009, for incremental effects of reconstruction in Japanese). In ongoing research, we are thus investigating the online processing of minimal pairs such as *kein Student hat nicht* (*no student has not*) in (1-b). In line with the analysis provided above we expect incremental effects.

An important issue not addressed in the present article concerns predictive processing. Meanwhile, a large number of psycho- and neurolinguistic studies have demonstrated that the human sentence processing system makes use of contextual information not only in an incremental manner but is able to make rather specific predictions about how the unfolding sentence most probably continues (see, e.g. the review in Kamide 2008). The proposed continuation semantics may provide some ingredients in order to model the underlying interpretation processes. A natural extension of the system would consist in an evaluation of the whole space of possible instantiations of continuation variables in an open proposition (see also Schlenker 2008, for the closely related notion of *good finals* to yet incomplete sentences or discourses). To indicate what we have in mind let us briefly consider the following two examples:

(82) a. The man has drunk. . .   (context: a full and an empty glass)
      b. Bach was born in every. . .

Experiments by Altmann & Kamide (2007) have shown that during processing (82-a) comprehenders immediately look at the empty glass. Obviously, this is due to the meaning of the perfect form of *drink*: Any sensible completion of the sentence has to involve a theme argument that can be linked to a result state of a drink event. Imposing this restriction on the possible continuations in the given context acts as an immediate filter and singles out the empty glass as the only possible referent. We think that the proposed

framework could well be extended to model such a filter mechanism. What is required – besides an analysis of the perfect in the continuation format – is a proper way to use the contextual information in order to generate the set of possible, i.e. consistent, instantiations of the continuation variables in the future derivation steps.

We think that something along the same lines must go on in (82-b), too. The crucial point in this example is that the rest of the sentence is not necessary to evaluate that (82-b) does not make any sense even though *every* cannot be composed with the beginning of the sentence on any account we are aware of.[11] That the sentence fragment does not make sense results from two contradictory presuppositions. The first is that *to be born* presupposes a unique place of birth, whereas *every* triggers the strong expectation that the restrictor set must consist of more than one place. The example is thus somewhat similar to the case of aspectual mismatch in Russian discussed above, where two incompatible presuppositions were imposed on the same predication. In a sense, this was done in a predictive manner before having processed its actual content yet.

To conclude, we would like to point out again that the proposed analysis is by far not unique, and that there are alternative frameworks such as Combinatorial Categorial Grammar (CCG, e.g. Steedman 2001), Tree Adjoining Grammar (TAG, e.g. Joshi & Schabes 1997) supplemented with a compositional semantics (e.g. LTAG, Joshi, Kallmeyer & Romero 2007) or Dynamic Syntax (Kempson, Meyer-Viol & Gabbay 2000, Cann, Kempson & Marten 2005). All of them have been successfully applied to psycholinguistic data (see, e.g. Demberg, Keller & Koller (2013)) not only for syntactic parsing but also for some aspects of event semantic interpretation (Sayeed & Demberg 2013). However, what sets the present proposal apart from existing ones is that it is the first that allows the incremental construction of Neo-Davidsonian event representations in interaction with quantifier interpretation resting upon minimal syntactic assumptions. We hope that the framework can be successfully applied to other semantic phenomena beyond those discussed in the present paper.

Appendix A on unrestrained beta reduction: compositionality and the reification of assignment functions

In the text above we did not present any details about how unrestrained beta-reduction is possible. As this technique is essential to the viability of the approach, and as the details are far from trivial, it is only fair for a reader to demand to see them. Due to limitations of space, we cannot do justice to this demand in full but will only present the main ideas and refer the reader to Klein & Sternefeld (2013) for details and formal proofs.

Our starting point is the well known fact that the usual truth conditions of predicate logic are not stated in a strictly compositional way. The reason for this is that variable

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[11]We are grateful to Bernhard Schwarz for providing this example as well as valuable suggestions concerning its incremental interpretation very similar in spirit to the explanation sketched above.

binding is not compositional: since both the open formula $P(x)$ and the closed formula $\forall x P(x)$ have the logical type t, there is no compositional way to calculate the truth value of the sentence from that of the open formula. What is needed or added in the classical framework is assignment functions for variables.

Given such functions we can formulate compositional truth conditions (cf. Zimmermann & Sternefeld 2013, ch. 10), but, in that case, assignment functions themselves must be talked about when stating the truth conditions and thus become part of the ontology. This reification of assignment functions is standard in the algebraic approach to logic since Henkin & Tarski (1961). The standard practice is to interpret an open formula like $P(x)$ as the set of assignment functions that satisfy $P(x)$. Accordingly, existential quantification roughly says that this set of assignment functions is not empty.

In Zimmermann & Sternefeld (2013) the compositional truth conditions are stated in the meta-language; another perhaps more transparent way to capture what is going on is to represent them in a formal language: using standard lambda calculus, the set of assignments that satisfy a formula $P(x_1, x_2)$ is denoted by its characteristic function $\lambda g P(g(x_1), g(x_2))$, where g is a function from variables to entities in the domain D. This kind of notation has first been used for linguistic purposes by Bennett (1977). Observe that the role of variables in this system slightly differs from the standard approach: variables no longer are interpreted themselves by assignments, but can rather be treated as constants, or entitities on their own which must be given an interpretation in the ontology. In Zimmermann & Sternefeld (2013) it is therefore assumed that such variables are entities that denote themselves, while Bennett replaces a variable x_i by the integer i which of course is a name for (and therefore denotes) the natural number i. Accordingly, the translation of $P(x_i, x_j)$ corresponds to $\lambda g P(g(i), g(j))$, where i and j are constants (!) that denote natural numbers. The model theoretic universe is thus sorted into a domain D and the set of natural numbers (previously called variables).

Let us adopt the convention to use integers as a kind of pseudo-variable—also called pointers or discourse referents in other frameworks. The important insight that emerges from these representations is that the integers formally function as constants rather than as variables.

We may now specify a translation function $\mathbf{T}$ from predicate logic into our sorted lambda language as follows:

(83)   a. $\mathbf{T}(x_i) = \lambda g.g(i)$
       b. $\mathbf{T}(P(x_{1_i}, \ldots x_{n_j})) = \lambda g.P(\mathbf{T}(x_{1_i})(g), \ldots, \mathbf{T}(x_{n_j})(g))$
       c. $\mathbf{T}(\neg\alpha) = \lambda g \neg \mathbf{T}(\alpha)(g)$
       d. $\mathbf{T}((\alpha \wedge \beta)) = \lambda g(\mathbf{T}(\alpha)(g) \wedge \mathbf{T}(\beta)(g))$
       e. $\mathbf{T}(\forall y \phi) = \lambda g \forall y \mathbf{T}(\phi)(g[i/y])$ where $g[n/x]$ is the modified assignment defined in (84):

(84) $g[n/x] := (\iota f)(f(n) = x \wedge \forall i(i \neq n \rightarrow f(i) = g(i)))$

Example:

(85) $\mathbf{T}(\forall x_2 P(x_5, x_2)) = \lambda g \forall x_2 P(\lambda g. g(5)(g[2/x_2]), \lambda g. g(2)(g[2/x_2])) =$
      $\lambda g \forall x_2 P(g[2/x_2](5), g[2/x_2](2)) = \lambda g \forall x_2 P(g(5), x_2)$

Note that in ordinary predicate logic, formulas have type t, in the translation they have type $\langle\langle n, e\rangle, t\rangle$ where n is the logical type of a variable. As the translation of a variable x_i is $\lambda g. g(i)$, its logical type is $\langle\langle n, e\rangle, e\rangle$. This type shifted semantics is an indirect but equivalent interpretation of ordinary predicate logic.

The next step is crucial and does the basic trick to make beta reduction work in the desired fashion. Let us add lambda abstraction to predicate logic and consider the equation in (86):

(86) $\forall x_i(\mathbf{man}(x_i) \to \mathbf{snore}(x_i)) = \lambda\phi\forall x_i(\mathbf{man}(x) \to \phi)(\mathbf{snore}(x_i))$

This is a case of illicit β-reduction. But now consider the tanslation of the argument of the lambda term, namely $\lambda g.\mathbf{snore}(g(i))$, which contains no free variable at all. Hence, this term is amenable for reduction in the corresponding translation (87):

(87) $\lambda\phi\lambda g\forall x_i(\mathbf{man}(x_i) \to \phi(g[i/x]))(\lambda g.\mathbf{snore}(g(i))) =$
      $\lambda g\forall x_i(\mathbf{man}(x_i) \to \lambda g.\mathbf{snore}(g(i)(g[i/x]))) =$
      $\lambda g\forall x_i(\mathbf{man}(x_i) \to \mathbf{snore}(g[i/x](i)) =$
      $\lambda g\forall x_i(\mathbf{man}(x_i) \to \mathbf{snore}(x_i))$

This is the basis for our claim that β-reduction can be unconstrained (cf. Sternefeld (2001) for an application to reconstruction phenomena).

Unfortunately, this is not the end of the story, rather it is only the beginning of complicated calculations. The reason for this additional complexity is that we have to give a translation not only for the few formulas we have seen above but for a fully typed language with lambda terms of different logical types and functional application; second, we have to prove the translations of any application of a lambda term to an argument to be in fact logically equivalent with the unrestrained beta reduction of the argument. Neither the translation nor the proof are trivial; we must confer the reader to Klein & Sternefeld (2013).

Appendix B on coindexation

Appendix A has introduced beta reduction of β into the scope of a quantifier α. Clearly, the intended effect only eventuates if there is some way to state that the variable quantified by α occurs in β, otherwise quantification would be vacuous and the result unintended. Hence, our grammar must contain some means to identify variables, e.g. by coindexation as above. This applies to quantification over events as well as over individuals. In the

paper above, we did not explicitly identify events, because we restricted ourselves to only one designated variable e. Hence there was no need to identify variables. In the case of quantifying determiners, different DPs require different variables, hence, some syntactic identification mechanism is called for.

This seem to constitute an additional complication that is due to our particular choice of unconstrained beta reduction. However, we would like to argue briefly that there is independent motivation for a quite general mechanism of coindexation.

This motivation arises from the fact that open propositions, which at some stage of the derivation will feed a binder, normally are not interpreted in a way that would be independent of the identity of the free variable it contains.

In the standard systems, open formulae like $P(x)$ and $P(y)$ denote the sets of assignments that satisfy them; hence they have different denotations because the assigment functions for x and y differ. In a compositional semantics this is unwanted and there are ways to interpret these propositions as having the same denotations, cf. Klein & Sternefeld (in press). However, if indeed it can be maintained that the denotations of $P(x)$ and $Q(y)$ are the same (a theory we did not presuppose in this paper since it would constitute a major departure from current practice), combining them into more complex formulae, e.g. by conjunction, requires a decision as to whether the result is $P(x) \land Q(y)$ or $P(x) \land Q(x)$. Only in the latter case did we "identify" argument positions by coindexation. Such identifications are called "coordinations" in Fine (2007). They are part of the semantics of conjunction in Klein & Sternefeld (in press).

In our paper we rely on such coordinations, because the general format of all building blocks is based on open propositions: if we strip off the lambda prefix $\lambda c \lambda p$ what remains is a proposition, and crucially an open one. Hence some way of variable management is indispensable, and indeed the coindexing convention we used in section 3 is only a simplified result of a much longer story about alphabetic innocence that independently motivates the use of coordinations.

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