For-Adverbials and Aspectual Interpretation: An LTAG Analysis Using Hybrid Logic and Frame Semantics

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Abstract In this paper, we propose to use Hybrid Logic (HL) as a means to combine frame-based lexical semantics with quantification. We integrate this into a syntax-semantics interface using LTAG (Lexicalized Tree Adjoining Grammar) and show that this architecture allows a fine-grained description of event structures by quantifying, for instance, over subevents. As a case study, we provide an analysis of *for*-adverbials and the aspectual interpretations they induce. The basic idea is that *for*-adverbials introduce a universal quantification over subevents that are characterized by the predication contributed by the verb. Depending on whether these subevents are bounded or not, the resulting overall event is then an iteration or a progression. We show that by combining the HL approach with standard techniques of underspecification and by using HL to formulate general constraints on event frames, we can account for the aspectual coercion triggered by these adverbials. Furthermore, by pairing this with syntactic building blocks in LTAG, we provide a working syntax-semantics interface for these phenomena.

Keywords aspectual coercion · *for*-adverbials · iteration · Frame Semantics · Hybrid Logic · Lexicalized Tree Adjoining Grammar

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1 Introduction

1.1 *For*-Adverbials and Aspectual Reinterpretation

An important topic for theories of aspectual composition and coercion is the interaction of lexical aspect (*Aktionsart*) and temporal adverbials. On the one hand, *in*- and *for*-adverbials have been used since Vendler

(1957:145f) as indicators for distinguishing between activities and accomplishments. On the other hand, there are many types of sentences in which a temporal adverbial is not compatible with the lexical aspect of the verb but which have nevertheless a regular interpretation (see, e.g., Egg 2005). For example, while in (1a), the verb *cry* denotes an activity and is thus immediately compatible with the *for*-adverbial, the verb *cough* in (1b) is semelfactive, that is, it denotes a punctual event, and, hence, calls for additional adjustments in order to be compatible with *for*-adverbials.

(1) a. Peter cried for ten minutes.
 b. Peter coughed for ten minutes.

In the case of (1b), the adjustment consists in interpreting the sentence as describing a sequence or iteration of coughings.

The semantic composition of *for*-adverbials with atelic predicates such as *sit*, *cry* or *swim* can be modeled straightforwardly by letting the *for*-adverbial assign a certain time span to the denoted state, process or activity. Punctual and telic predicates (semelfactives, achievements, accomplishments), on the other hand, do not satisfy the sortal requirements of *for*-adverbials and, hence, need to undergo aspectual coercion when combined with such adverbials. Dölling (2014) presents an elaborate approach along these lines, which provides various coercion mechanisms for turning telic predicates into atelic ones, including the *iteration coercion* and the *habitual coercion*. For example, the iterative coercion is realized by means of the following second-order term (cf. Dölling 2014:206):

(2) $\lambda P \lambda e[\forall e'(\textit{is-constituent-of}(e', e) \rightarrow P(e'))]$

When applied to P, the resulting predicate denotes events whose constituents satisfy P. Dölling's model requires the constituents to be temporally adjacent in order to constitute a process or activity. This assumption has the consequence that semelfactives (*cough*, *knock*, *jump*), which are analyzed as *moments* without duration, need to get "stretched" to *episodes* before the iteration coercion can apply. That is, iterative interpretations of semelfactives require a two-step coercion in Dölling's approach.

While Dölling does not say much about the impact of coercion on cognitive processing costs, the approaches of Deo & Piñango (2011) and Champollion (2013) aim at being more predictive in this respect. Deo & Piñango suggest that the main processing issue for an iterative interpretation of a telic predicate, when combined with a *for*-adverbial, lies in the identification of a contextually determined regular temporal partition of the specified time span. For instance, the iterative interpretation of the sentence in (3) depends on a regular partitioning of the three months into reasonably small subintervals, each of which is associated with an event of John biking to the office.

(3) John biked to the office for three months.

Deo & Piñango do not assume that iterative readings of *for*-adverbial constructions depend on telic or atelic properties of the event description. In fact, they explicitly deny the need for inserting a coercion operator for the interpretation of expressions like (3) and (1b). However, the logical representation proposed by Deo & Piñango does not differ so much from Dölling's coercion operator in (2), except that they quantify over subintervals instead of event constituents. The crucial point is that for Deo & Piñango, the quantification is already introduced by the *for*-adverbial, irrespective of the type of predicate it applies to. Deo & Piñango distinguish between *iterative* and *continuous* readings of *for*-adverbials, where a continuous reading requires an atelic predicate as in (1a). They assume that iterative readings call for a contextually determined partition of the time interval while continuous readings go along with a context-independent "infinitesimal" partition.

Under this analysis, iterative readings do indeed not depend on the telicity or atelicity of the predicate. Continuous interpretations, however, are apparently sensitive to the aspectual properties of the verb since they are licensed by atelic predicates only. Champollion (2013) takes up this issue and provides further evidence for the fact that the missing aspectual sensitivity in Deo & Piñango's approach leads to undesired consequences. Champollion tries to remedy these problems by the following modifictions: first, he postulates a silent iteration operator, which means "once or repeatedly," that turns semelfactive and telic predicates into atelic ones. Second, he assumes that *for*-adverbials introduce a vague but context-independent partition $\mathscr{R}_I^{short(I)}$ of the specified temporal interval I into reasonably short subintervals The meaning of an adverbial like *for three months* is then represented as follows (cf. Champollion 2013:445):

(4) $\lambda P \lambda I[months(I) = 3 \wedge AT(P, I) \wedge \forall J[J \in \mathscr{R}_I^{short(I)} \rightarrow AT(P, J)]]$

Here, $AT(P, I)$ roughly means that P holds at I, which in the case of event predicates comes down to saying that there is an event of type P whose runtime is I. Since (4) requires P to hold at the whole interval and at each cell of the partition, it follows that P is *not quantized* (in the sense of Krifka 1998); hence, it is not telic. That is, *for*-adverbials select atelic predicates according to Champollion's analysis, which is the reason for applying the iteration operator in the case of telic predicates. Note that the partition of the interval can be coarser than the decomposition of the iteration into elementary events; repetitions may occur within a single cell of the partition. If, for example, I is an interval of 10 minutes and $\mathscr{R}_I^{short(I)}$ consists of cells of 30 seconds then (1b) is true if one or more coughings of Peter occur within each of the 30 second cells (under the above assumption that the silent iteration operator has been applied to the semelfactive predicate).

The described analysis is problematic for examples like (3) since the partition $\mathscr{R}_I^{short(I)}$ is independent of the context. In (3), it is not clear whether John biked to the office every day, twice a day, every second day, every week, or according to another schedule. It can thus happen that there is no biking of John to the office in some of the cells of $\mathscr{R}_I^{short(I)}$. This is why the partition operator of Deo & Piñango has a contextual parameter. Champollion (2013:446) also postulates a separate, context-dependent partition operator, but only for situations where the reference of indefinites covaries with the cells of the partition, as in example (5a).

(5) a. We built a huge snowman in our front yard for several years.
b. She bounced a ball for twenty minutes.

Zucchi & White (2001) and Kratzer (2007), among others, observed that *for*-adverbials tend to take narrow semantic scope with respect to the quantifiers in their syntactic scope. This implies a non-covarying interpretation of indefinites as in (5b). The narrow-scope covariation of the indefinite in the preferred reading of (5a) is thus an exception that calls for an explanation. Champollion's suggestion to put the burden at least partly on an additional, contextually specified partition seems problematic since the contextual parameter is already required for examples like (3), as mentioned above.

1.2 Goals and Outline

In this paper, we present a revised analysis of *for*-adverbials and develop a formal model of their compositional integration at the syntax-semantics interface. The proposed semantic representation combines several aspects of the approaches discussed in the previous section: like Dölling, we directly refer to event components instead of temporal subintervals. Similar to Deo & Piñango and Champollion, we assume that the universal quantification over event components is already contributed by the *for*-adverbial. Like Dölling and Deo & Piñango, we do not postulate an iteration operator. Like Dölling and Champollion, we take into account the aspectual sensitivity of *for*-adverbials. The semantic representations used in this paper are motivated by frame-semantic considerations and will be formalized in the language of *Hybrid Logic* (HL). This language allows us to express constraints over event types and to quantify over event components. The syntax-semantics interface is modelled within the framework of *Lexicalized Tree Adjoining Grammar* (LTAG) combined with underspecification on the level of HL formulas.

The structure of the paper is as follows. Section 2 introduces HL as a language for describing frame structures. Section 3 describes the architecture used for modelling the syntax-semantics interface. Within this framework, section 4 develops then an analysis of *for*-adverbials in combination with a uniform treatment of iteration and progression, along the lines sketched above. Section 5 concludes.

2 Semantic Frames and Hybrid Logic

2.1 Semantic Frames

Frames emerged as a representation format of conceptual and lexical knowledge (Fillmore 1982, Barsalou 1992, Löbner 2014). They are commonly presented as semantic graphs with labelled nodes and edges, as in figure 1, where nodes correspond to entities (individuals, events, ...) and edges to (functional or non-functional) relations between these entities. In figure 1 all relations except *part-of* are meant to be functional. This representation offers a fine-grained and systematic decomposition of meaning that goes beyond what is usually represented in FrameNet frames (Osswald & Van Valin Jr. 2014). Frames can be formalized as extended typed feature structures (Petersen 2006, Kallmeyer & Osswald 2013) and specified as models of a suitable logical language, the *labelled attribute-value description language* (LAVD language). Such a language allows for the composition of lexical frames on the sentential level by means of an explicit syntax-semantics interface (Kallmeyer & Osswald 2013). Yet, this logical framework does not provide means for the lexical items to introduce explicit quantification.

As Blackburn (1993) points out, attribute-value structures can also be described using another logical language: *Hybrid Logic* (HL, see Areces & ten Cate 2007), an extension of the language of modal logic, well-suited to the description of graph structures like the one of figure 1. HL introduces *nominals*, that is, node names, that allow the logical formulas to refer to specific nodes of the graph. The nominal n_0 for instance refers to the *locomotion* node in figure 1. It is then possible, for example, to specify that the AGENT and the MOVER edges from the node n_0 should meet on the same node in figure 1. This additional expressiveness of HL over modal logic allows one to express node sharing in attribute-value structures (Blackburn 1993). HL is an established logical formalism which has been extensively studied, in particular with respect to the addition of *variables* for nodes, and the associated *quantifiers*, that can appear in the logical formulas. Its relation to attribute-value structures and its expressiveness make it a natural candidate to relate quantified expressions and frame semantics.

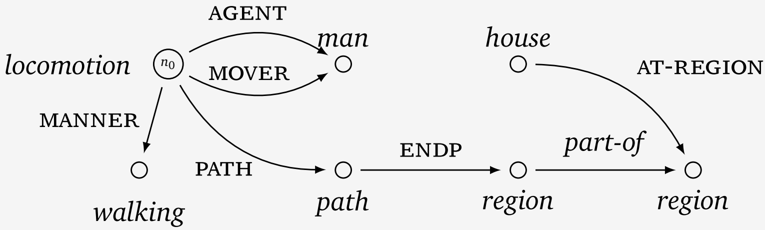

Figure 1 Frame compatible with the sense of *The man walked to the house* (adapted from Kallmeyer & Osswald 2013)

Compared to Kallmeyer & Osswald 2013, the approach we propose here does not consider frames as “genuine semantic representations.” The one-to-one equivalence between the logical formulas of the LAVD language of Kallmeyer & Osswald (2013) and the frames as graph (or relational) structures relies on the existence of minimal models for such formulas. While HL with nominals, but without variables and binders, is very close to the LAVD language, it is not obvious what the notion of minimal model becomes when using quantification. Thus, we have a more traditional view where the sense of an expression is a hybrid logical formula and its reference is computed against models. The latter are the frames we wish to consider. But, contrary to what happens with minimal models, they are then not fully specified by the logical formulas which serve as frame descriptions.

2.2 Frame Description with Hybrid Logic

Before giving the formal definition of Hybrid Logic as used in this paper, let us illustrate the different possibilities HL offers to express properties of frames. Consider the model $\mathscr{M}_1$ given in figure 1. In this model, we have edges labeled with functional relations (AGENT, MOVER etc.) and one edge labeled with a non-functional relation, *part-of*, indicated by lowercase. (Note that HL formulas do not distinguish between the two types of edge labels. That is, functionality has to be enforced by additional contraints.) As in standard modal logic, we can talk about propositions holding at single nodes. This allows for specifying types, in the Frame Semantics sense, assigned to single nodes as *proposition*. For instance, in $\mathscr{M}_1$, the formula *region* is true at the two nodes in the bottom-right corner but false at all other nodes of $\mathscr{M}_1$. Furthermore, we can talk about the existence of an attribute for a node. This corresponds to stating there exists an edge originating at this node using the $\diamond$ modality in modal logic. In frames, there may be several relations, hence several modalities, denoted by $\langle R \rangle$ where R is the name of the relation. For example, $\langle \text{AGENT} \rangle man$ is true in $\mathscr{M}_1$ at the *locomotion* node n_0 because there is an AGENT edge from n_0 to some other node where *man* holds. But it is false at all other nodes. Finally, we can have conjunction, disjunction, and negation of these formulas. For example, $locomotion \wedge \langle \text{MANNER} \rangle walking \wedge \langle \text{PATH} \rangle \langle \text{ENDP} \rangle \top$ is also true at the *locomotion* node n_0.[1]

HL extends this with the possibility to name nodes in order to refer back to them without following a specific path, and with quantification over nodes. Let us exemplify this again with formulas evaluated with respect to $\mathcal{M}_1$. In the following, we use a set of nominals, that is, of node names, and a set of node variables. n_0 is such a nominal, the node assigned to it is the locomotion node in $\mathcal{M}_1$. $x, y, \ldots$ are node variables. The truth of a formula is given with respect to a specific node w of a model $\mathcal{M}$, an assignment V from nominals to nodes in the model and an assignment g which maps variables to nodes in $\mathcal{M}$.

There are different ways to state existential quantifications in HL, for instance, $\mathbf{\exists}\phi$ and $\exists x.\phi$. $\mathbf{\exists}\phi$ is true at w if there exists a node w' in $\mathcal{M}$ at which ϕ holds. In other words, we move to some node w' in the frame and there ϕ is true. $\mathbf{\exists}$*house* is, for instance, true at any node in $\mathcal{M}_1$. As usual, we define $\mathbf{\forall}\phi \equiv \neg\mathbf{\exists}(\neg\phi)$. Then $\mathbf{\forall}(\mathit{path} \rightarrow \langle \text{ENDP} \rangle \top)$ holds at any node in $\mathcal{M}_1$. In contrast to $\mathbf{\exists}\phi$, $\exists x.\phi$ is true at w if there is a w' such that ϕ is true at w under an assignment $g^x_{w'}$ which maps x to w'. In other words, there is a node that we name x but for the evaluation of ϕ, we do not move to that node. For example, the formula $\exists x.\langle \text{PATH} \rangle \langle \text{ENDP} \rangle \langle \mathit{part\text{-}of} \rangle (x \wedge \mathit{region}) \wedge \mathbf{\exists}(\mathit{house} \wedge \langle \text{AT-REGION} \rangle x)$ is true at the *locomotion* node in $\mathcal{M}_1$.

Besides quantification, HL also allows us to use nominals or variables to refer to nodes: $@_n\phi$ specifies the moving to the node w denoted by n before evaluating ϕ. n can be either a nominal or a variable. The $\downarrow$ operator allows us to assign the current node to a variable: $\downarrow x.\phi$ is true at w if ϕ is true at w under the assignment g^x_w. That is, we call the node we are located at x, and, under this assignment, ϕ is true at that node. For example, $\langle \text{PATH} \rangle \langle \text{ENDP} \rangle \langle \mathit{part\text{-}of} \rangle (\downarrow x.\mathit{region} \wedge \mathbf{\exists}(\mathit{house} \wedge \langle \text{AT-REGION} \rangle x))$ is true at the *locomotion* node in $\mathcal{M}_1$.

By employing this logic, we can characterize the frame of figure 1 by the formula (6). More precisely, any model that satisfies formula (6) can

[1] $\top$ is the proposition that is true at any node. So $\langle \text{PATH} \rangle \langle \text{ENDP} \rangle \top$ is true at a node if we can reach from it some node following first a PATH edge then a ENDP edge.

be unified with the frame of figure I at node n_0.

(6) $@_{n_0} \mathit{locomotion}$
$\wedge (\exists x.\langle \textsc{agent} \rangle (x \wedge \mathit{man}) \wedge \langle \textsc{mover} \rangle x)$
$\wedge \langle \textsc{manner} \rangle \mathit{walking}$
$\wedge (\exists x.\langle \textsc{path} \rangle (\mathit{path} \wedge \langle \textsc{endp} \rangle (\mathit{region} \wedge \langle \mathit{part\text{-}of} \rangle (x \wedge \mathit{region})))$
$\wedge \mathbf{E}(\mathit{house} \wedge \langle \textsc{at-region} \rangle x))$

Alternatively, as shown in (7), we can use the ↓ operator instead of the two ∃ operators since we know how to reach the two nodes we want to refer to several times. The first time we talk about them, we give them some name via the ↓ operator and this allows to refer to them again at some later point.

(7) $@_{n_0} \mathit{locomotion}$
$\wedge \langle \textsc{agent} \rangle (\downarrow x.\mathit{man} \wedge @_{n_0} \langle \textsc{mover} \rangle x)$
$\wedge \langle \textsc{manner} \rangle \mathit{walking}$
$\wedge \langle \textsc{path} \rangle (\mathit{path} \wedge \langle \textsc{endp} \rangle (\mathit{region} \wedge \langle \mathit{part\text{-}of} \rangle (\downarrow x.\mathit{region}$
$\wedge \mathbf{E}(\mathit{house} \wedge \langle \textsc{at-region} \rangle x))))$

As can be seen from this example, HL allows us to express path equations (see the $\langle \textsc{agent} \rangle$ and $\langle \textsc{mover} \rangle$ attributes of n_0). However, the way these path equations are expressed is rather tedious compared to other feature logics. Therefore we define

$$\langle \textsc{r}^1_1 \rangle \ldots \langle \textsc{r}^1_k \rangle \doteq \langle \textsc{r}^2_1 \rangle \ldots \langle \textsc{r}^2_l \rangle \equiv \exists x(\langle \textsc{r}^1_1 \rangle \ldots \langle \textsc{r}^1_k \rangle x \wedge \langle \textsc{r}^2_1 \rangle \ldots \langle \textsc{r}^2_l \rangle x)$$

Using this notation, the HL characterization of $\mathscr{M}_1$ is (8).

(8) $@_{n_0} \mathit{locomotion}$
$\wedge \langle \textsc{agent} \rangle \doteq \langle \textsc{mover} \rangle$
$\wedge \langle \textsc{agent} \rangle \mathit{man}$
$\wedge \langle \textsc{manner} \rangle \mathit{walking}$
$\wedge \langle \textsc{path} \rangle (\mathit{path} \wedge \langle \textsc{endp} \rangle (\mathit{region} \wedge \langle \mathit{part\text{-}of} \rangle (\downarrow x.\mathit{region}$
$\wedge \mathbf{E}(\mathit{house} \wedge \langle \textsc{at-region} \rangle x))))$

2.3 Hybrid Logic

We slightly adapt the notations of Areces & ten Cate (2007).

Definition 1 (Formulas) *Let* $\mathsf{Rel} = \mathsf{Func} \cup \mathsf{PropRel}$ *be a set of functional and non-functional relation symbols,* Type *a set of type symbols,* Nom *a set of nominals (node names), and* Nvar *a set of node variables, with* $\mathsf{Node} = \mathsf{Nom} \cup \mathsf{Nvar}$. *Formulas are defined as:*

$$\mathsf{Forms} ::= \top \mid p \mid n \mid \neg\phi \mid \phi_1 \wedge \phi_2 \mid \langle R\rangle\phi \mid \mathbf{E}\phi \mid @_n\phi \mid \downarrow x.\phi \mid \exists x.\phi$$

where $p \in \mathsf{Type}$, $n \in \mathsf{Node}$, $x \in \mathsf{Nvar}$, $R \in \mathsf{Rel}$ *and* $\phi, \phi_1, \phi_2 \in \mathsf{Forms}$. *Moreover, we define:*

- $\mathbf{A}\phi \equiv \neg\mathbf{E}\neg\phi$
- $[R]\phi \equiv \neg\langle R\rangle\neg\phi$
- $\phi \rightarrow \psi \equiv \neg\phi \vee \psi$
- $\langle R^1_1\rangle \ldots \langle R^1_k\rangle \doteq \langle R^2_1\rangle \ldots \langle R^2_l\rangle \equiv \exists x(\langle R^1_1\rangle \ldots \langle R^1_k\rangle x \wedge \langle R^2_1\rangle \ldots \langle R^2_l\rangle x)$

We call $\mathbf{A}$ *and* $[R]$ *universal operators, and* $\mathbf{E}$ *and* $\langle R\rangle$ *existential operators. The elements of* Func *will be written in small caps.*

Definition 2 (Model, assignment) *A* model $\mathcal{M} = \langle M, (R^{\mathcal{M}})_{R\in\mathsf{Rel}}, V\rangle$ *is a triple such that*

1. *M is a non-empty set,*
2. *each $R^{\mathcal{M}}$ is a binary relation on M, and*
3. *the valuation $V : \mathsf{Type} \cup \mathsf{Nom} \longrightarrow \wp(M)$ is such that if $i \in \mathsf{Nom}$ then $V(i)$ is a singleton.*

An assignment g *is a mapping* $g : \mathsf{Nvar} \longrightarrow M$. *For an assignment* g, g^x_m *is an assignment that differs from* g *at most on* x *and* $g^x_m(x) = m$. *For* $n \in \mathsf{Node}$, *we also define* $[n]^{\mathcal{M},g}$ *to be the only* m *such that* $V(n) = \{m\}$ *if* $n \in \mathsf{Nom}$ *and* $[n]^{\mathcal{M},g} = g(n)$ *if* $n \in \mathsf{Nvar}$.

As can be seen from these definitions, nominals are, on the one hand, similar to variables since they allow us to access nodes via the @ operator, and on the other hand, they are similar to propositions, that is, to types, except that they are special propositions that hold only at a single node.

Now we can define satisfaction of a formula at a specific node in a model, given some assignment g.

Definition 3 (Satisfaction)

1. *Let $\mathcal{M}$ be a model, $w \in M$, and g an assignment for $\mathcal{M}$. The satisfaction relation of a formula ϕ by the model $\mathcal{M}$, with the assignment g at the node w ($\mathcal{M}, g, w \vDash \phi$) is defined as follows:*

$$\begin{array}{ll}
\mathcal{M}, g, w \vDash \top & \\
\mathcal{M}, g, w \vDash p & \textit{iff } w \in V(p) \textit{ for } p \in \mathsf{Type} \\
\mathcal{M}, g, w \vDash n & \textit{iff } w = [n]^{\mathcal{M},g} \textit{ for } n \in \mathsf{Node} \\
\mathcal{M}, g, w \vDash @_n\phi & \textit{iff } \mathcal{M}, g, [n]^{\mathcal{M},g} \vDash \phi \textit{ for } n \in \mathsf{Node} \\
\mathcal{M}, g, w \vDash \neg\phi & \textit{iff } \mathcal{M}, g, w \nvDash \phi \\
\mathcal{M}, g, w \vDash \downarrow x.\phi & \textit{iff } \mathcal{M}, g^x_w, w \vDash \phi \\
\mathcal{M}, g, w \vDash \phi_1 \wedge \phi_2 & \textit{iff } \mathcal{M}, g, w \vDash \phi_1 \textit{ and } \mathcal{M}, g, w \vDash \phi_2 \\
\mathcal{M}, g, w \vDash \exists x.\phi & \textit{iff } \exists w' \; \mathcal{M}, g^x_{w'}, w \vDash \phi \\
\mathcal{M}, g, w \vDash \langle R \rangle \phi & \textit{iff } \exists w' \; R^{\mathcal{M}}(w, w') \textit{ and } \mathcal{M}, g, w' \vDash \phi \\
\mathcal{M}, g, w \vDash \boldsymbol{\exists}\phi & \textit{iff } \exists w' \; \mathcal{M}, g, w' \vDash \phi
\end{array}$$

2. *A formula ϕ is:*
   - satisfiable *if there is a model $\mathcal{M}$, and assignment g on $\mathcal{M}$, and a node $w \in M$ such that $\mathcal{M}, g, w \vDash \phi$;*
   - globally true *in a model $\mathcal{M}$ under an assignment g, that is, $\mathcal{M}, g, w \vDash \phi$ for all $w \in M$. We write $\mathcal{M}, g \vDash \phi$.*

With these definitions, we also obtain

$$\mathcal{M}, g, w \vDash \boldsymbol{\forall}\phi \text{ iff } \forall w' \; \mathcal{M}, g, w' \vDash \phi$$

2.4 Expressive Power

According to the satisfaction relation definition, $\downarrow$ and $\exists$ bind node variables without changing the current evaluation node. In addition to $\boldsymbol{\exists}$, Blackburn & Seligman (1995) introduce another quantifier Σ for which the satisfaction relation also changes the evaluation node:[2]

$$\mathcal{M}, g, w \vDash \Sigma x.\phi \text{ iff } \exists w' \; \mathcal{M}, g^x_{w'}, w' \vDash \phi$$

[2]Blackburn & Seligman (1995) call $\boldsymbol{\exists}$ the *somewhere* operator, and write it $\Diamond$, and $\boldsymbol{\forall}$ is the *universal* modality, written $\Box$.

This defines two independent families of operators: $\downarrow$ and $\exists$, and $\boldsymbol{\exists}$ and Σ.[3] However, using any operators of both families (for instance $\downarrow$ and $\boldsymbol{\exists}$, the "weakest" ones) is expressively equivalent to using the most expressive fragment of the hybrid languages (the full hybrid language).

It is usual to refer to the hybrid languages $\mathcal{H}(\theta_1, \ldots, \theta_n)$ as the extension of the modal language with nominals and the operators $\theta_1, \ldots, \theta_n \in \{\downarrow, @, \boldsymbol{\exists}, \exists\}$. It is worth noting that even using the simplest binder $\downarrow$ already causes the satisfiability problem for $\mathcal{H}(\downarrow)$ to be undecidable (Areces et al. 1999). There are, however, syntactic restrictions on formulas that make the satisfiability problem decidable. In particular, formulas of the full hybrid language that do not contain the pattern "universal operator scoping over a $\downarrow$ operator scoping over a universal operator" have a decidable satisfiability problem (ten Cate & Franceschet 2005). All of the formulas we build in our account of iteration and progression in combination with *for*-adverbial avoid this pattern. This might not be the case in the general use of HL for quantification by Kallmeyer et al. (2015) in sentences such as *every politician in every city*... However, for every hybrid language, testing a given formula against a given model remains decidable (Franceschet & de Rijke 2006).

3 The Syntax-Semantics Interface for LTAG and HL

3.1 Introduction to LTAG

A *Lexicalized Tree Adjoining Grammar* (LTAG; Joshi & Schabes 1997, Abeillé & Rambow 2000) consists of a finite set of *elementary trees*. Larger trees can be derived via the composition operations *substitution* (replacing a leaf with a tree) and *adjunction* (replacing an internal node with a tree). An adjoining tree has a unique non-terminal leaf that is its *foot node* (marked with an asterisk). When adjoining such a tree to some node n, in the resulting tree, the subtree with root n from the original tree ends up below the foot node. A sample LTAG derivation is given in figure 2. The subject and object NP slots in the *ate* tree are replaced with the *Peter* and *pizza* trees respectively (*substitution*) and the *always* tree adjoins at the VP node of the *ate* tree.

[3] Note that $\downarrow$ can be defined in terms of $\exists$ by $\downarrow x.\phi \equiv \exists x.x \wedge \phi$ and that $\boldsymbol{\exists}$ can be defined in terms of Σ by $\boldsymbol{\exists}\phi \equiv \Sigma z.\phi$ with z not occurring in ϕ.

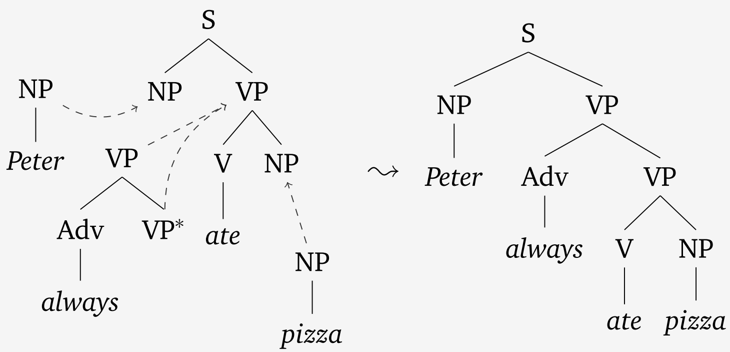

Figure 2 Sample LTAG derivation

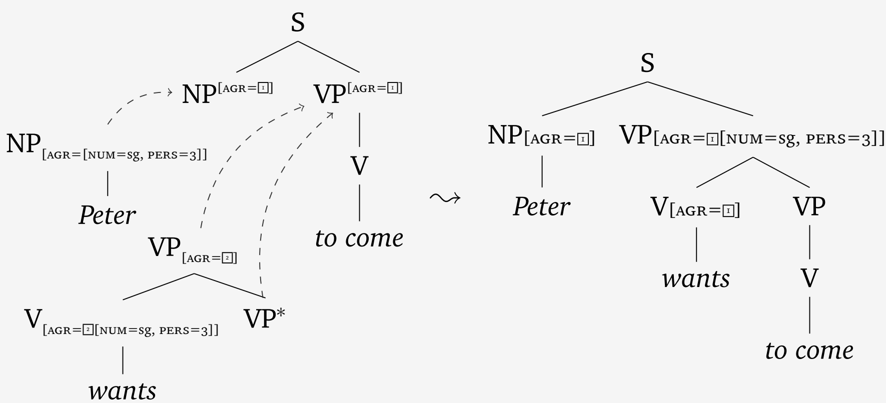

Figure 3 LTAG derivation with feature structures

In order to capture syntactic generalizations, the non-terminal node labels are enriched with feature structures (Vijay-Shanker & Joshi 1988). Each node has a top and a bottom feature structure (except substitution nodes, which have only a top). Nodes in the same elementary tree can share features. Substitutions and adjunctions trigger unifications: in a substitution step, the top of the root of the substituted tree unifies with the top of the substitution node. In an adjunction step, the top of the root of the adjoining tree unifies with the top of the adjunction site and the bottom of the foot of the adjoining tree unifies with the bottom of the adjunction site. Furthermore, in the final derived tree, top and bottom must unify in all nodes. Figure 3 provides an example (top feature structures are superscripts and bottom feature structures are subscripts). The AGR feature of the V node of *wants* is passed to the root of the auxiliary tree. Then, by adjunction and subsequent top-bottom unification on the highest VP node, its value unifies with [1] in the *to come* tree and thereby gets passed to the subject node. By substitution and subsequent top-bottom unification at the NP slot, it unifies then with the AGR feature at the root of the *Peter* tree. The tree on the right is the one we obtain after derivation and top-bottom unification on all nodes.

3.2 The Syntax-Semantics Interface

Our architecture for the interface between TAG syntax and frame semantics builds on previous approaches which pair each elementary tree with a semantic representation that consists of a set of formulas, in this case, HL formulas. An example is given in figure 4. We use interface features on the syntactic nodes that are responsible for triggering semantic composition via the feature unifications during substitution and adjunction. These features are, for instance, I (for "individual") and E (for "event"). Their values can be nominals or variables from the HL formula linked to the elementary tree they occur in. If their values are not yet known, we can use a boxed number as a variable and indicate structure sharing via this variable. These boxed numbers can also occur in the HL formulas. Once a value is assigned to them via syntactic composition, their occurrence in the HL formula is also replaced with this value. This unification-based assignment is the only mechanism for semantic composition.

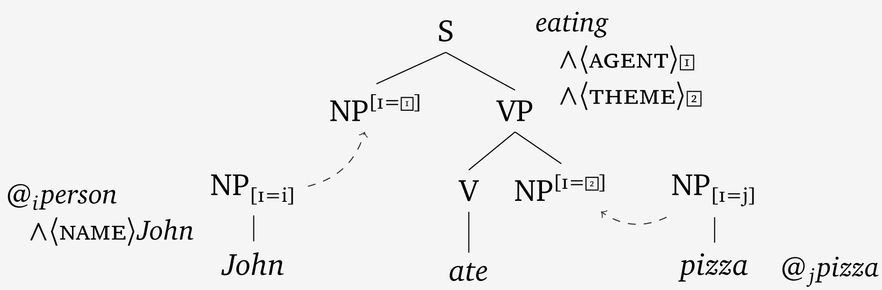

Figure 4 HL-based syntax-semantics interface

The example in figure 4 is rather simple. The elementary tree of *ate* and its associated HL formula tell us that the nominal or variable of the AGENT node is contributed by whatever is substituted at the subject node while the THEME node will be further specified by the object NP. Both NP trees contain a nominal and contribute this nominal via the I interface feature. Substitution and final top-bottom unification unify [I=$\boxed{1}$] with [I=i] and [I=$\boxed{2}$] with [I=j]. As a consequence, i is assigned to $\boxed{1}$ and j to $\boxed{2}$ and we obtain a collection of three HL formulas, $eating \wedge \langle \text{AGENT} \rangle i \wedge \langle \text{THEME} \rangle j$, $@_i person \wedge \langle \text{NAME} \rangle John$ and $@_j pizza$. These are then interpreted conjunctively.

3.3 Underspecified Representations

In figure 4, the boxed variables in the HL formulas act like holes that are replaced with concrete formulas (here, the two nominals) once the syntax-triggered unifications are performed. In general, we want to be able to insert also other formulas into these holes, not just variables and nominals. Therefore, we introduce the possibility to label HL formulas, using labels l_0, l_1, etc. A label is the name of a unique HL formula. But it does not, as in the case of nominals, denote a single element in the frame; the formula can hold at several frame nodes. Using these labels as values in our interface features, we can insert these formulas in larger formulas via composition. Besides these labels, we also introduce the possibility to express dominance constraints of the form $\boxed{i} \lhd^* x$ where x is either a boxed variable (= a hole) or a label. The relation $\lhd^*$ is the dominance relation in the syntactic tree of the HL formula $\boxed{i}$ occurs in, that is, it expresses a relation "is subformula of" on the HL formulas. This extension is an application of well-known underspecification techniques, in particular *hole semantics* (Bos 1995). Similar proposals for LTAG semantics but with standard predicate logic and not with frames and HL have already been made by Gardent & Kallmeyer (2003), Kallmeyer & Joshi (2003), and Kallmeyer & Romero (2008).

As a basic example, consider the derivation given in figure 5. The *every* tree adjoins to the root of the *dog* tree and the derived tree substitutes into the subject slot of the *barked* tree. The interface feature MINS determines the minimal scope for attaching quantifiers, and the feature E stands for the event/predication contributed at a specific node. The syntactic unifications lead to $\boxed{4} = x$, $\boxed{2} = l_2$, $\boxed{3} = l_1$. As a result of these equations, we

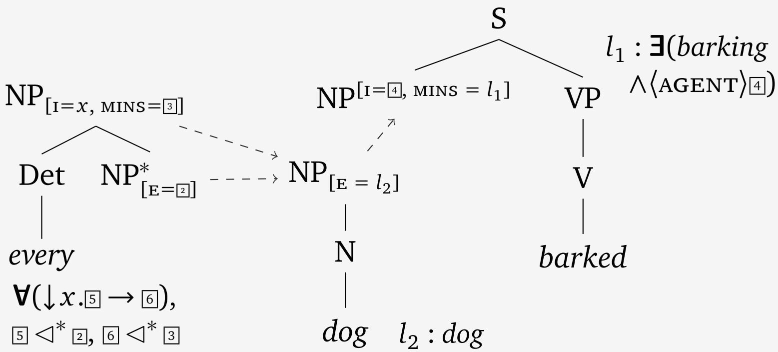

Figure 5 Derivation of *every dog barked*

obtain the following underspecified representation:

(9) $\forall(\downarrow x.\boxed{5} \rightarrow \boxed{6}), l_2 : dog, l_1 : \exists(barking \wedge \langle \textsc{agent} \rangle x), \boxed{5} \lhd^* l_2, \boxed{6} \lhd^* l_1$

The representation in (9) has a unique solution (i.e., a unique fully specified HL formula that satisfies the constraints in (9)) given by the mapping $\boxed{5} \mapsto l_2, \boxed{6} \mapsto l_1$, which leads to (10).

(10) $\forall(\downarrow x.dog \rightarrow \exists(barking \wedge \langle \textsc{agent} \rangle x))$

Obviously, this way to underspecify subformula relations in the semantic representation allows standard underspecified representations for scope ambiguities.

In the next section, we will see that underspecification via dominance constraints also allows us to account for cases in event semantics where certain characterizations of events are underspecified as to whether they refer to the entire event or to subevents. The particular combination of frame description in HL and underspecification brings sufficient expressive power to (a) allow for a fine-grained event decomposition and for quantification over subevents, and (b) link embedded subevents and the entire event via dominance constraints and thereby enable adverbials to apply in-between. Furthermore, underspecification in the event types, in combination with appropriate HL constraints, allows us to underspecify the type of the event resulting from applying a *for*-adverbial while making this type dependent on the type of the embedded event.

Besides frame descriptions linked to elementary trees, our grammar also contains general constraints on frames that hold universally and independently of syntax. These constraints can, for instance, describe subtype relations of the form $\forall locomotion \rightarrow motion$; mandatory attributes for certain types, such as $\forall motion \rightarrow \langle \textsc{mover} \rangle \top$; or mandatory path equations for certain types, for example $\forall locomotion \rightarrow \langle \textsc{agent} \rangle \doteq \langle \textsc{mover} \rangle$.

4 Application to *for*-Adverbials

4.1 *For*-Adverbials and Atelic Events

We start with a basic case of a *for*-adverbial modifying an atelic event description:

(11) Peter swam for one hour.

We take *swimming* to be represented by a frame described by $swimming \wedge \langle \textsc{agent} \rangle \boxed{2}$. Furthermore, we need an existential quantification over the event such that the semantic representation for *Peter swam*, for instance, is $@_i(person \wedge \langle \textsc{name} \rangle Peter) \wedge \exists(swimming \wedge \langle \textsc{agent} \rangle i)$. This existential quantifier does not necessarily immediately embed the event characterization coming from the verb since some adverbial taking this event node into its scope could attach to it. Therefore, we assume a kind of event-internal scope window between the existential quantification and the event node. Figure 6 shows the *swam* tree with its HL formula. In the formula, there is a hole $\boxed{3}$ in the scope of the existential $\exists$, and the formula labeled l_2, which describes the *swimming* node, has to be below $\boxed{3}$ (constraint $\boxed{3} \lhd^* l_2$). If no adverbial is added, then l_2 gets assigned to $\boxed{3}$.

We assume that *swimming* is a subtype of the event type *progression*, which characterizes continuous nonbounded events:[4]

(12) $\forall(swimming \rightarrow progression)$
$\forall(progression \rightarrow nonbounded)$

---

[4]We prefer "*non*bounded" over "*un*bounded" in order to avoid the connotation of limitlessness that comes with the latter term (see also Jackendoff 1996). For purposes of this paper, we do not distinguish between atelicity and nonboundedness but we are aware that there are good reasons to do so in general (see, for instance, Cappelle & Declerck 2005 and the references therein).

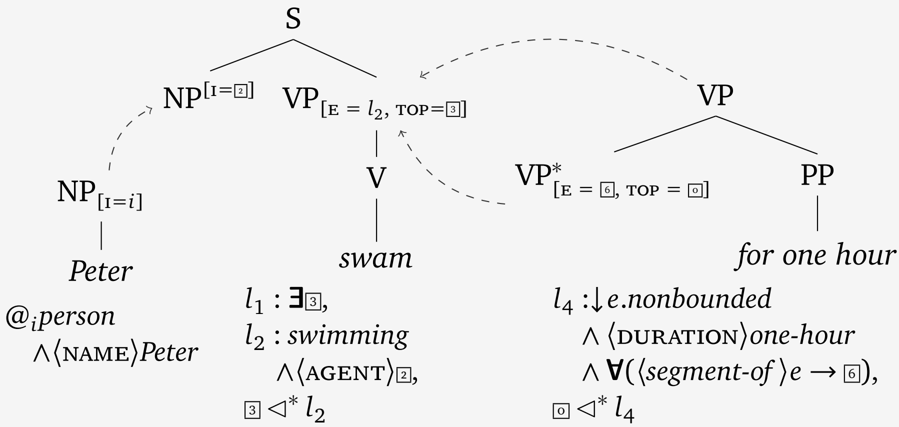

Figure 6 Derivation for (11)

Following the outline sketched in section 1.2, the meaning of the adverbial *for one hour* is represented as follows:[5]

(13) $\downarrow e.nonbounded \wedge \langle \textsc{duration} \rangle\, one\text{-}hour \wedge \forall(\langle segment\text{-}of \rangle e \rightarrow P)$

More precisely, (13) is paired with an elementary tree, as depicted in the right of figure 6, and P stands for a hole (in this case, $\boxed{6}$), which will be filled by the formula associated with the modified VP, here l_2.

We may assume that events of type *progression* have a sufficently rich subeventual structure that is closed under sum formation. For the present purpose, we only need the property that every progression is an event segment of itself:

(14) $\forall(\downarrow e.progression \rightarrow \langle segment\text{-}of \rangle e)$

[5]As pointed out by an anonymous reviewer, formula (13) could be expressed equivalently in the following, more compact form by employing the universal modality and the inverse of the relation *segment-of*:

$$nonbounded \wedge \langle \textsc{duration} \rangle\, one\text{-}hour \wedge [segment\text{-}of^{-1}]\, P$$

However, we do not introduce the inversion operator to our logic in this paper. Moreover, this transformation cannot be systematized as it would, for instance, break the compositionality for sentences with multiple quantifiers (Kallmeyer et al. 2015).

By means of (14), it follows that in the example under discussion, the whole one-hour event is of type *swimming*. We will see in the next section that this is different for iterations.

The substitution and adjunction in figure 6 trigger the unifications $\boxed{0} = \boxed{3}, \boxed{2} = i, \boxed{6} = l_2$ on the interface features. As a result, when applying these and collecting the formulas, we obtain the following underspecified semantic formulas:

(15) $@_i person \wedge \langle \textsc{name} \rangle Peter,$
$l_1 : \exists \boxed{3}, l_2 : swimming \wedge \langle \textsc{agent} \rangle i,$
$l_4 : \downarrow e.nonbounded \wedge \langle \textsc{duration} \rangle one\text{-}hour$
$\wedge \forall (\langle segment\text{-}of \rangle e \rightarrow l_2),$
$\boxed{3} \lhd^* l_4, \boxed{3} \lhd^* l_2$

The only possible disambiguation mapping is $\boxed{3} \mapsto l_4$, which yields, with an additional conjunctive interpretation of the set, the formula (16):

(16) $@_i person \wedge \langle \textsc{name} \rangle Peter$
$\wedge \exists \downarrow e.(nonbounded \wedge \langle \textsc{duration} \rangle one\text{-}hour$
$\wedge \forall (\langle segment\text{-}of \rangle e \rightarrow swimming \wedge \langle \textsc{agent} \rangle i))$

Furthermore, given (14), $swimming \wedge \langle \textsc{agent} \rangle i$ also holds at e.

4.2 Punctual Events and *for*-Adverbials

Now we consider cases where a *for*-adverbial combines with a punctual event description. In this case, the event is reinterpreted as an iteration.

(17) Peter knocked at the door for ten minutes.

The meaning of (17) is that we have an iteration of knocking events, each of them involving Peter as an agent and the same door as a patient, and that the entire iteration goes on for ten minutes:

(18) $\exists (\downarrow e.iteration \wedge \langle \textsc{duration} \rangle ten\text{-}minutes \wedge \langle \textsc{agent} \rangle i \wedge \langle \textsc{patient} \rangle j$
$\wedge \forall (\langle segment\text{-}of \rangle e \rightarrow knocking \wedge \langle \textsc{agent} \rangle i \wedge \langle \textsc{patient} \rangle j))$
$\wedge @_i (person \wedge \langle \textsc{name} \rangle Peter) \wedge @_j door$

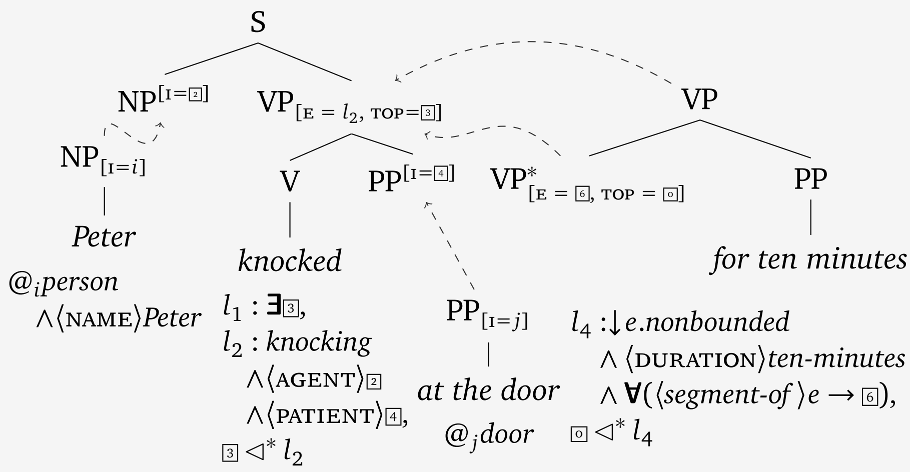

Figure 7 Derivation for (17)

Formula (18), however, leaves several aspects of iterations implicit. Firstly, we need to exclude the possibility that an iteration has no or only one segment. For this reason, following Dölling (2014), we assume that iterations consist of at least two segments:

(19) $$\forall(\downarrow e.\mathit{iteration} \rightarrow \exists(\downarrow e_1.\langle \mathit{segment\text{-}of} \rangle e \wedge \exists(\downarrow e_2.\langle \mathit{segment\text{-}of} \rangle e \wedge \neg @_{e_1} e_2)))$$

Besides this, the single segments must be distributed over the entire iteration in some regular way. We assume that the specification of what, for a specific type of iteration, "on a regular basis" means, is contextually given. We will not spell this out in this paper. Note that we do not require the segments of an iteration to be adjacent (in contrast to Dölling 2014). Typically, there are temporal gaps between the segments of an iteration. In particular, events of type *progression* and *iteration* are subject to different constraints on how their segments are related to each other.

Iterations, like progressions, are conceived of as nonbounded events and, hence, they satisfy the selectional restrictions of *for*-adverbials; recall (13). Furthermore, the following constraints make sure that every event of type *nonbounded* is either an *iteration* or a *progression* and that it cannot be both at the same time:

(20) $\forall(nonbounded \longleftrightarrow iteration \vee progression)$
$\forall(iteration \rightarrow \neg progression)$

The derivation of (17) shown in figure 7 yields (21).

(21) $\exists \boxed{3}, l_2 : knocking \wedge \langle \text{AGENT} \rangle i \wedge \langle \text{PATIENT} \rangle j,$
$l_4 : \downarrow e.nonbounded \wedge \langle \text{DURATION} \rangle ten\text{-}minutes$
$\wedge \forall(\langle segment\text{-}of \rangle e \rightarrow l_2),$
$@_i(person \wedge \langle \text{NAME} \rangle Peter), @_j door,$
$\boxed{3} \lhd^* l_2, \boxed{3} \lhd^* l_4$

The only possible mapping is $\boxed{3} \mapsto l_4$, which leads, with a conjunctive interpretation of the resulting set, to (22).

(22) $\exists(\downarrow e.nonbounded \wedge \langle \text{DURATION} \rangle ten\text{-}minutes$
$\wedge \forall(\langle segment\text{-}of \rangle e \rightarrow knocking \wedge \langle \text{AGENT} \rangle i \wedge \langle \text{PATIENT} \rangle j))$
$\wedge @_i(person \wedge \langle \text{NAME} \rangle Peter) \wedge @_j door$

We further adopt additional constraints on iterations and progressions concerning the possible types of their segments:

(23) $\forall(\langle segment\text{-}of \rangle iteration \rightarrow bounded)$
$\forall(punctual \rightarrow bounded)$
$\forall(\langle segment\text{-}of \rangle progression \rightarrow nonbounded)$
$\forall(nonbounded \rightarrow \neg bounded)$

Moreover, we have $\forall(knocking \rightarrow punctual)$. With these constraints, e in (22) is necessarily of type *iteration* since its segments are of type *knocking*.

The given analysis does not make use of an explicit iteration operator, which is in line with Dölling 2014 and Deo & Piñango 2011 but in contrast to Champollion 2013 (see section 1). In the derivation shown in figure 7, the nonbounded event introduced by the *for*-adverbial is identified as being of type *iteration* based on the event type of the modified VP and the constraints listed in (20) and (23). Events of type *iteration* are subject to specific constraints on their inner structure, among which is the constraint stated in (19).

4.3 Bounded Events and *for*-Adverbials

More interesting though similar cases of bounded events that are iterated are, for example, (24).

(24) John biked to the office for three months.

Processing such examples seems to be more difficult than processing sentences as (17). As for the way the *for*-adverbial combines with the *John biked to the office* event, we keep the analysis from section 4.2: *John biked to the office* is a bounded event and, when embedded under the *for*-adverbial, it is extended to an iteration.

The crucial difference from *knock* in (17) is that the verb *bike* itself does not describe a bounded event. *Bike* without any additional goal specification is an event of type *progression*. The event boundary in (24) comes from the additional information provided by the PP *to the office*. This PP specifies the end of the path of the described movement and thereby delimits the event.

We now no longer want the type *progression* to be automatically inferred for all motion events of type *swimming* or *biking*. Instead, such motion events can become bounded if a goal is added, as formalized by the following constraints:

(25) $\forall(\mathit{biking} \rightarrow \mathit{motion})$
$\forall(\mathit{motion} \wedge \langle\textsc{goal}\rangle\top \rightarrow \mathit{bounded})$
$\forall(\mathit{motion} \wedge \langle\textsc{path}\rangle\top \rightarrow \mathit{directed\text{-}motion})$
$\forall(\mathit{directed\text{-}motion} \wedge \neg\langle\textsc{path}\rangle\langle\textsc{endp}\rangle\top \rightarrow \mathit{nonbounded})$
$\forall(\mathit{directed\text{-}motion} \wedge \mathit{nonbounded} \rightarrow \mathit{progression})$

The analysis of (24) in figure 8 is similar to the directed motion analyses proposed in Kallmeyer & Osswald 2013. The elementary tree used for *biked* in this analysis is the specific tree for the directed motion construction where a directional PP contributes the goal of the movement. In addition to contributing the goal, the PP also specifies some properties of the path, namely that its endpoint lies in the AT-REGION of the office. Given (25), the event of type *biking* in (24) is also of type *bounded* and consequently, the application of the *for*-adverbial triggers the creation of a node of type

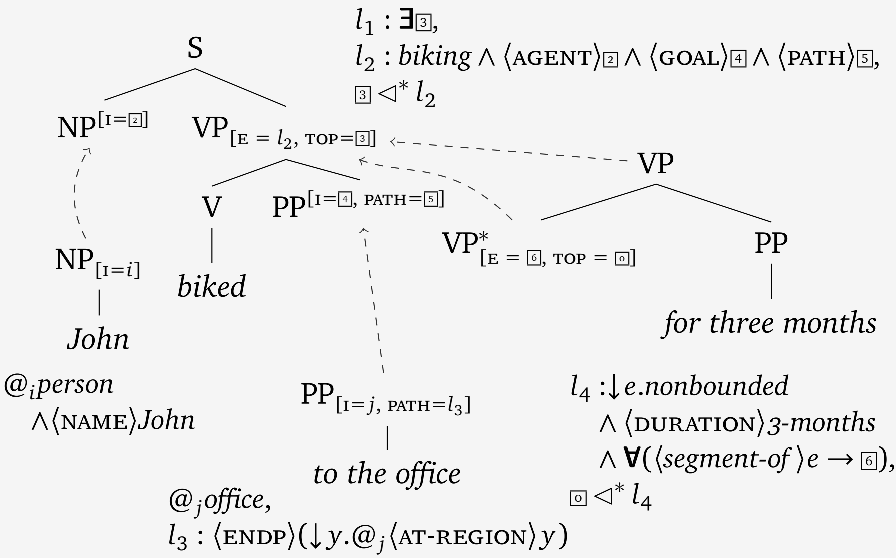

Figure 8 Derivation for (24)

iteration.

The underspecified semantic representation we obtain with the derivation in Fig. 8 is given in (26):

(26) $@_i person \wedge \langle \textsc{name} \rangle John,\ @_j office,$

$l_1 : \exists \boxed{3},$

$l_2 : biking \wedge \langle \textsc{agent} \rangle i \wedge \langle \textsc{goal} \rangle j \wedge \langle \textsc{path} \rangle l_3,$

$l_3 : \langle \textsc{endp} \rangle (\downarrow y. @_j \langle \textsc{at-region} \rangle y)$

$l_4 : \downarrow e.nonbounded \wedge \langle \textsc{duration} \rangle 3\text{-}months$

$\wedge \forall (\langle segment\text{-}of \rangle e \rightarrow l_2),$

$\boxed{3} \lhd^* l_2,\ \boxed{3} \lhd^* l_4$

The only possible disambiguation is $\boxed{3} \mapsto l_4$, which yields, under a conjunctive interpretation, to (27):

(27) $@_i person \wedge \langle \textsc{name} \rangle John \wedge @_j office,$
$\wedge \exists \downarrow e.nonbounded \wedge \langle \textsc{duration} \rangle 3\text{-}months$
$\wedge \forall(\langle segment\text{-}of \rangle e \rightarrow biking \wedge \langle \textsc{agent} \rangle i \wedge \langle \textsc{goal} \rangle j$
$\wedge \langle \textsc{path} \rangle \langle \textsc{endp} \rangle (\downarrow y.@_j \langle \textsc{at-region} \rangle y))$

Due to the existence of the GOAL and the PATH, we can infer that the *biking* events are in this case *bounded directed-motion* events. Consequently the entire event has to be an *iteration*.

4.4 Interaction with the Scope of Indefinites

As mentioned in section 1.1, indefinites usually do not take narrow scope with respect to a *for*-adverbial in the way they can have different scope with respect to other adverbials or quantifiers. In the examples in (28) (from Kratzer 2007), the indefinite always scopes over the adverbial.

(28) a. John pushed a cart for an hour.
b. I dialed a wrong phone number for five minutes.
c. She bounced a ball for 20 minutes.

The following example (taken from Zucchi & White 2001) shows that in cases where a narrow scope reading would be preferred for plausibility reasons, it is nevertheless not possible if no clue is available from context or world knowledge of how to partition the interval:

(29) ??John found a flea on his dog for a month.

Before discussing our analysis, let us have a look at the proposal in Champollion 2013.

(30) John dialed a wrong phone number for five minutes.

For (30), Champollion proposes the representation in (31).

(31) $\lambda I[\exists e \exists x[number(x) \wedge {}^*dial(e, john, x) \wedge I = \tau(e)$
$\wedge\, minutes(I) = 5 \wedge \forall J[J \in \mathscr{R}_I^{short(I)}$
$\rightarrow \exists e' \exists y[number(y) \wedge {}^*dial(e, john, y) \wedge J = \tau(e')]]]]$

The existential $\exists x$ is taken to be part of the P predicate in the semantics

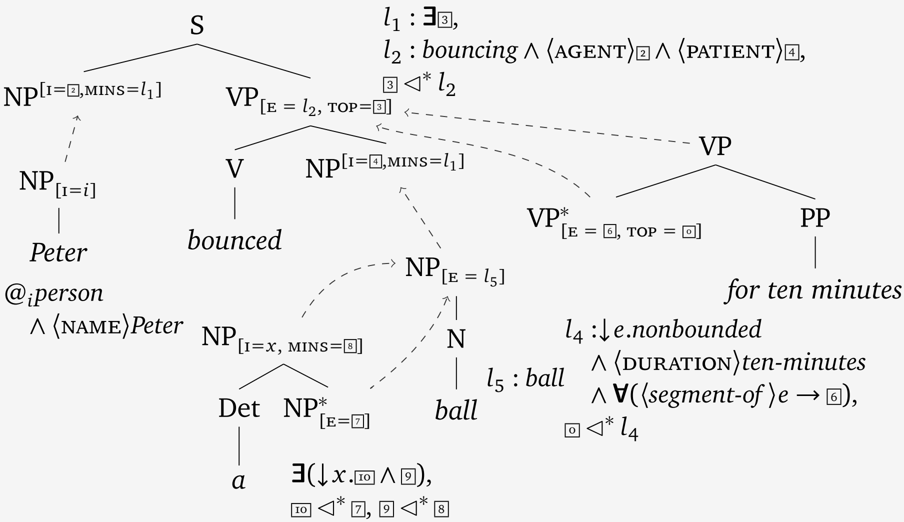

Figure 9 Derivation for (32)

of the *for*-adverbial. Since one part of the *for*-semantics requires P to hold at the entire interval I, one correctly obtains that there is a single phone number $number_I$ that has been dialed repeatedly over the interval I. However, in the predicates that apply to the smaller time intervals J, there is also an existential quantification $\exists y$ over phone numbers and the dialing here applies to y, not to x. In other words, in every shorter interval J, there has been a repeated dialing of some number $number_J$ that is possibly different from $number_I$. This is at least unnecessary and goes against what the meaning of *for*-adverbials is supposed to capture, namely that the same number has been dialed in each of these smaller time intervals. But without any additional postulate, (31) does not prevent there to be intervals among the J during which there was no dialing of $number_I$.

Our analysis avoids the second existential quantification in the scope of the universal quantification coming from the *for*-adverbial. Therefore, each subevent involves the same x as the entire event. Let us explain our analysis with the example (32).

(32) Peter bounced a ball for ten minutes.

In the analysis of quantifiers in figure 5, the quantifier gets its minimal scope from some interface feature MINS. According to figure 5, the value of this feature is the label of the ∃ formula associated with the verbal predicate. If this is adapted to (32), the prediction is that indefinites have scope over the *for*-adverbial.

The derivation of (32) is given in figure 9. The label l_1 of the ∃ formula introducing the event node is passed to the quantifier as its minimal scope via the interface feature MINS. Due to the unification of interface variables during substitution and adjunction and due to the final top-bottom unification, we obtain the result that $\boxed{8}$ (the minimal scope of the indefinite) gets identified with l_1 while the *for*-adverbial gets embedded under $\boxed{3}$, which is the scope of the ∃-formula labeled l_1. In other words, the predicate *bounce* contributes two scope windows: a scope window for quantifiers with a lower limit given by the MINS feature and a lower scope window inside the event structure, delimited by the TOP feature and the E value. *For*-adverbials target this lower scope window since they modify the internal structure of the event.

As a result, we obtain the underspecified HL formula in (33):

(33) $@_i person \wedge \langle \textsc{name} \rangle Peter,$
$l_1 : \exists \boxed{3},\ l_2 : bouncing \wedge \langle \textsc{agent} \rangle i \wedge \langle \textsc{patient} \rangle x,$
$\exists(\downarrow x. \boxed{10} \wedge \boxed{9}), l_5 : ball,$
$l_4 : \downarrow e.nonbounded \wedge \langle \textsc{duration} \rangle ten\text{-}minutes$
$\wedge \forall(\langle segment\text{-}of \rangle e \rightarrow l_2),$
$\boxed{3} \lhd^* l_4, \boxed{10} \lhd^* l_5, \boxed{9} \lhd^* l_1, \boxed{3} \lhd^* l_2$

The only possible disambiguation, $\boxed{10} \mapsto l_5$, $\boxed{9} \mapsto l_1$, $\boxed{3} \mapsto l_4$, yields (34):

(34) $@_i person \wedge \langle \textsc{name} \rangle Peter$
$\wedge \exists(\downarrow x.ball \wedge \exists \downarrow e.nonbounded \wedge \langle \textsc{duration} \rangle ten\text{-}minutes$
$\wedge \forall(\langle segment\text{-}of \rangle e \rightarrow bouncing \wedge \langle \textsc{agent} \rangle i \wedge \langle \textsc{patient} \rangle x))$

This analysis correctly predicts that a quantifier can have narrow scope with respect to a second quantifier since both target the same scope window. However, they both have to scope over a *for*-adverbial.

(35) Every boy bounced a ball for ten minutes.

For (35), in our analysis, we obtain the underspecified formula in (36).

(36) $l_1 : \exists \boxed{3}, l_2 : bouncing \wedge \langle \text{AGENT} \rangle x \wedge \langle \text{PATIENT} \rangle y,$
$\forall(\downarrow x.\boxed{10} \rightarrow \boxed{9}), l_5 : boy, \exists(\downarrow y.\boxed{11} \wedge \boxed{12}), l_6 : ball,$
$l_4 :\downarrow e.nonbounded \wedge \langle \text{DURATION} \rangle ten\text{-}minutes$
$\wedge \forall(\langle segment\text{-}of \rangle e \rightarrow l_2),$
$\boxed{3} \lhd^* l_4, \boxed{10} \lhd^* l_5, \boxed{9} \lhd^* l_1, \boxed{11} \lhd^* l_6, \boxed{12} \lhd^* l_1, \boxed{3} \lhd^* l_2$

The dominance constraints from (36) are depicted in figure 10. Here, we can see clearly that the scope window for the two quantifiers where the scope order of the universal and the existential is underspecified is higher than the universal quantification coming from the *for*-adverbial.

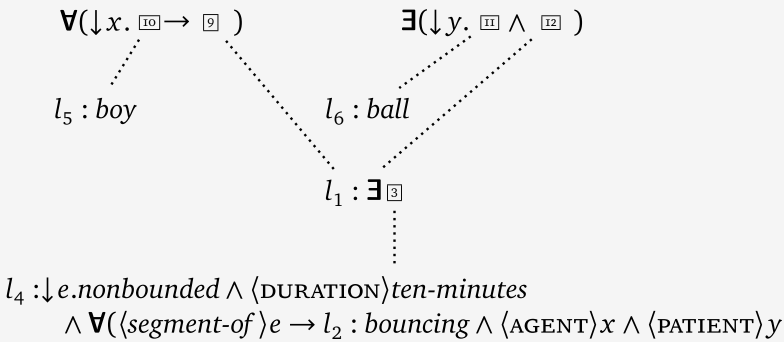

Figure 10 Dominance constraints from (36)

5 Conclusion

The frame-semantic perspective supports a fine-grained and structured characterization of semantic components. By using Hybrid Logic as a description language, we added quantification to frame semantics while preserving the original object-centered view. We applied this formalism to the analysis of *for*-adverbials and their interaction with the aspectual properties of the modified verb phrases. Moreover, by allowing underspecified formulas, we integrated our analysis into a fully compositional model of the syntax-semantics interface within the LTAG framework.

In the proposed model, the semantic representation of *for*-adverbials selects for nonbounded events and comes with a universal quantification over event components. Based on the event type of the modified VP and general semantic constraints on the types of events and their event components, the correct type of the overall phrase (i.e., iteration vs. progression) can be inferred without assuming an additional iteration operator or the like. Finally, we have shown how our model can cope with the specific scopal behavior that *for*-adverbials show with respective to indefinites.

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