(eds.), Layered structure and reference in a functional perspective, 73-97. Amsterdam: Benjamins.
- (1993). Epistemic modal adverbs and adjectives and the layered representation of conceptual and linguistic structure. Manuscript, Univ. of Antwerp.
- (i.p.). Epistemic modal qualifications: Some linguistic and conceptual issues. Book in prep.
Palmer, F.R. (1986). Mood and modality. Cambridge: CUP.
Perkins, M. (1983). Modal expressions in English. London: Pinter.
Valin, R. Van (1990). Layered syntax in role and reference grammar. In J.Nuyts et al. (eds.), Layers and levels of representation in language theory, 193-232. Amsterdam: Benjamins.

1993. CLS 29, Volume 2: The Parasession (What We Think, What We Mean, and How We Say It: Papers from the Parasession on the Correspondence of Conceptual, Semantic and Grammatical Representations), ed. Katharine Beals, Gina Cooke, David Kathman, Sotaro Kita, Karl-Erik McCullough, and David Testen, 287-303.

Paths and their names

Christopher J. Piñón
Stanford University

• PATH 1: a track made by the frequent or habitual use of men or animals : a trodden way ...
4a: the way or course traversed by something : route

Webster's *Third New International*

This study addresses the claim that a notion of PATH plays a significant role in natural language semantics.[0] According to Jackendoff, paths crucially figure in the analysis of (dynamic) PPs in English. Specifically, such PPs are said to refer to paths. In §1, a simple algebraic semantic analysis with paths is given for one type of path expression. In §2, Jackendoff's work serves as the basis for a critical discussion of the full typology of paths. Finally, in §3, the mereological semantic account developed in §1 is used to shed light on the 'parameters of difference' between path types.

1 Path semantics

The notion of PATH is a popular one, typically invoked in the analysis of English sentences containing a motion verb and a PP, as in

(1) Mary ran to the library,
(2) Rebecca swam from the dock.

The basic idea, most clearly attributable to Ray Jackendoff (1983, 1990, 1991), is that such PPs are referential, and that they refer to paths. On this view, if the sentences in (1–2) express true propositions, then the individual denoted by the subject NP traverses (by running, swimming, etc.) a quantity of space that extends between a starting point and an endpoint. The choice of preposition (*to*, *from*, etc.) determines which of these two spatial points is made linguistically explicit: in (1), it is the endpoint (*the library*), and in (2), it is the starting point (*the dock*). The path is understood to be the quantity of space traversed.

Let us examine in more detail Jackendoff's (1983) claim that certain types of PPs are used referentially to pick out paths. This means that paths have the logical status of individuals, akin to OBJECTS (including persons), LOCATIONS, TIMES, and EVENTS. PPs correspond to conceptual constituents in his theory of conceptual structure. Conceptual constituents are designated with square brackets, e.g., [TO THE LIBRARY $_{PATH}$], which refer directly to #entities# in the PROJECTED WORLD, and not to entities in the REAL WORLD. Consequently, [TO THE LIBRARY $_{PATH}$] refers to #to-the-library $_{path}$# in the projected world.[1]

A formal semantic analogue can be constructed for the idea that paths are individuals. The basic strategy is to enrich the model structure so that it contains a *sorted* universe of entities, including paths.[2] Consequently, formal semantic representations make use of sorted predicates and variables, including path predicates and variables, which are interpreted with respect to an assignment function in a model. Since a model is generally identified with (some part of) the real world, a mediating projected world in Jackendoff's sense plays no role in semantic interpretation. Although this is an important philosophical difference between formal semantics and conceptual semantics, the argument in this paper does not crucially depend on the presence or absence of a projected world. I therefore make the convenient assumption that the project world is identical to the real world, and so the distinction between #paths# (in the projected world) and paths (in the real world) can be ignored. Henceforth, to say that paths are entities is to mean that they are entities in the real world, and that we perceive them as such.

1.1 Representing paths

A simple model-theoretic version of Jackendoff's path semantics might run as follows.[3] We adopt an event semantics in which verbs are analyzed as predicates of events (i.e., of semantic type <e,t>; Parsons 1990, Krifka 1989a,b). In this approach, a verb has syntactic arguments, but no semantic arguments. Thematically marked NPs have the semantic type of verbal modifiers, i.e., they are of type <<e,t>,<e,t>>. The aim is to treat PPs headed by P°s such as *to*, *from*, etc. (henceforth DYNAMIC prepositions) on a par with NPs. Thus, just as thematically marked NPs are analyzed as modifiers, so are PPs, hence the latter are also of type <<e,t>,<e,t>>. $\bar{\text{N}}$s, however, are predicates and denote sets of objects; they are of semantic type <e,t>. $\bar{\text{P}}$s receive a parallel treatment: they denote sets of paths and are of semantic type <e,t>. In sum, we have the following type assignments:

(3) V°: <e,t> VP: <e,t>
(Θ-marked) NP: <<e,t>,<e,t>> $\bar{\text{N}}$: <e,t>
PP: <<e,t>,<e,t>> $\bar{\text{P}}$: <e,t>

Let us now consider the analysis of a sentence like (1). The $\bar{\text{P}}$ *to the library* denotes a set of paths, viz., all those paths that end at the library. More formally, if p is introduced as a sorted variable over paths, then p is bound by the λ-operator in the logical representation of this predicate:

(4) [to the library $_{\bar{\text{P}}}$] ⇒ λp[to-the-library′(p)] (type <e,t>)

The formula in (4) is a (characteristic) function from paths (i.e., entities) to truth values: for any path p, it tells us whether or not p is a member of this set of paths.

Note that (1) does not entail a unique path of traversal for Mary—the meaning of the sentence does not tell us which exact path she followed to the library. This suggests that the PP *to the library* refers *indefinitely* to a path. One way of achieving this result is to represent the path variable p as existentially bound in the translation of the PP:[4]

(5) [[to the library $_{\bar{\text{P}}}$] $_{\text{PP}}$] ⇒
$\lambda Q \lambda e \exists p[Q(e) \wedge$ to-the-library′(p)] (type <<e,t>,<e,t>>)

This formula combines with a verbal predicate (type <e,t>) to yield a predicate of events (type <e,t>) which contains the proposition that there is a path p which is a to-the-library′ path. It is evident that the PP *from the dock* in (2) would receive an analogous translation.

Evidence in favor of the existential binding analysis comes from the interpretation of VP ellipsis in the second conjunct of conjoined sentences, as in

(6) Mary ran to the library, and Rebecca did too.
(Compare: Mary read a poem, and Rebecca did too.)

The meaning of (6) allows for Mary and Rebecca to have taken different paths to the library. This parallels the interpretation of indefinite NPs in such a construction: in the example for comparision, Mary and Rebecca could have read different poems. Thus, existential quantification over paths yields the desired reading.

The phenomenon of donkey anaphora provides more evidence for the claim that PPs headed by *to* make indefinite reference to paths. In this case, however, a higher quantifier arguably unselectively binds the path variable, just as it binds the object variable in the analogous case of indefinite NPs. We see this in

(7) Every$_i$ girl who went [to the library]$_i$ ran there$_i$,
(Compare: Every$_i$ girl who owns [a cat]$_i$ feeds it$_i$.)

where *there* is analyzed as a pro-PP for the *to*-phrase under discussion. Roughly, (7) means that every girl who went along some path to the library also ran along that (same) path. Naturally, the exact path traversed can vary with each girl in the context; this is the effect of binding by the quantifier *every*. Note the parallel with indefinite NPs in the example for comparison. To conclude, the analysis of such dynamic PPs as indefinites receives significant empirical support.

Since PPs, unlike NPs, do not have overt articles, there is no surface reflex of the existential quantifier in (5). To get from (4) to (5), we entertain the idea of a null indefinite article for PPs in [Spec, PP]. In particular, the semantic translation of this article would have to be

(8) $\varnothing_{\text{PP}/\bar{\text{P}}}$ ⇒
$\lambda Q \lambda Q' \lambda e \exists p[Q'(e) \wedge Q(p)]$ (type <<e,t>,<<e,t>,<e,t>>>)

This indefinite article is semantically a function from sets to modifiers (which are in turn functions from sets to sets). The expression in (5) is straightforwardly derived by functional application of the formula in (8) to that in (4).

The representation of *to the library* in (4) is still quite crude, however, for it obscures the compositional nature of the $\bar{\text{P}}$. Moreover, it does not capture the fact that a to-the-library′ path has an implicit starting point. To proceed further, we have to decide about the treatment of dynamic prepositions like *to* and *from*.[5] Suppose that we analyze such prepositions as denoting relations between paths and objects. A reasonable logical translation of the preposition *to* is then

(9) $to_{\text{P°}}$ ⇒
$\lambda u \lambda p[\text{End}(p) = u \wedge \exists u'[\text{Beg}(p) = u']]$ (type <e,<e,t>>),

where End and Beg designate (partial) functions from paths to their endpoints and starting points, respectively, and u, u' are sorted variables for objects. Here I draw an explicit analogy between an analysis of prepositions in a path semantics and a treatment of verbs in an event semantics. Specifically, functions like End or Beg are viewed as analogous to functions like Patient or Agent at the clause level. In both cases, their purpose is to relate two different sorts of entities (whether paths to objects, or events to objects).

The expression in (9) is a function from objects to sets of paths: for any object u, it defines a set of paths that each have some (implicit) u' as their starting point and u as their endpoint. The next step is to apply this formula to a semantic expression of type e. For simplicity, it is convenient to translate definite descriptions with the iota operator to yield expressions of type e. In this case, we depart from the stated treatment of NPs in (3) precisely because the preposition and not the NP bears the thematic information.[6] Functional application of the formula in (9) to the object denoted by *the library* yields

(10) $\lambda u \lambda p[\mathrm{End}(p) = u \wedge \exists u'[\mathrm{Beg}(p) = u']](\iota u[\mathrm{library}'(u)]) \rightarrow$
$\lambda p[\mathrm{End}(p) = u \wedge u = \iota u[\mathrm{library}'(u)] \wedge \exists u'[\mathrm{Beg}(p) = u']]$ (type <e,t>).

In this way, we get a more refined version of (4), i.e., a predicate of paths with implicit starting points and with endpoints that are identical to the library.

Further refinements of (10) can be added as necessary. For example, one might claim that prepositions like *to* actually denote relations between paths and *locations* of objects, in contrast to what is stated in (10).[7] On this view, if Mary runs to the library, then she traverses a path extending from some implicit starting location to the location of the library. We capture this intuition by introducing the EIGENPLACE FUNCTION Loc, a (partial) function from objects and times to the locations that they occupy at those times.[8] The location of the library at time t is consequently represented by $\mathrm{Loc}(\iota u[\mathrm{library}'(u)],t)$.[9] End and Beg are reconstrued to be functions from paths to locations. In sum, we now have the following three functions:

(11) Loc: objects × times → locations
End: paths → locations
Beg: paths → locations

We then revise the formula in (10) to contain sorted variables over locations, as in

(12) $\lambda l \lambda p[\mathrm{End}(p) = l \wedge \exists l'[\mathrm{Beg}(p) = l']](\mathrm{Loc}(\iota u[\mathrm{library}'(u)],t)) \rightarrow$
$\lambda p[\mathrm{End}(p) = l \wedge l = \mathrm{Loc}(\iota u[\mathrm{library}'(u)],t) \wedge \exists l'[\mathrm{Beg}(p) = l']]$ (type <e,t>).

The analysis of *from the dock* in (2) is similar, with the difference that the endpoint variable is existentially bound and the starting point is the location of the dock.[10]

Since (12) is essentially what we want for the $\overline{\mathrm{P}}$ *to the library*, let us turn to the representation of the VP in (1). We first apply the indefinite article for PPs given in (8) to the expression in (12), yielding

(13) $\lambda Q' \lambda e \exists p[Q'(e) \wedge \mathrm{End}(p) = l \wedge l = \mathrm{Loc}(\iota u[\mathrm{library}'(u)],t) \wedge$
$\exists l'[\mathrm{Beg}(p) = l']]$ (type <<e,t>,<e,t>>).

The next step is to apply the formula in (13) to a predicate of events. Recall that since verbs are analyzed as predicates of events, the translation of *ran* (ignoring tense) is $\lambda e[\mathrm{run}'(e)]$. The result of this functional application is

(14) $\lambda e \exists p[\mathrm{run}'(e) \wedge \mathrm{End}(p) = l \wedge l = \mathrm{Loc}(\iota u[\mathrm{library}'(u)],t) \wedge$
$\exists l'[\mathrm{Beg}(p) = l']]$ (type <e,t>).

The predicate in (14) is the translation of the VP *ran to the library*.

Bringing the subject NP *Mary* into the picture is straightforward. In addition to assigning this NP the semantic type of modifier (cf. (3)), we declare that *mary'* is the value of the (partial) function Agent:

(15) *Mary* ⇒
$\lambda Q \lambda e[Q(e) \wedge \mathrm{Agent}(e) = u \wedge u = \mathrm{mary}']$ (type <<e,t>,<e,t>>)

Applying this expression to the predicate in (14), we get

(16) $\lambda e \exists p[\mathrm{run}'(e) \wedge \mathrm{End}(p) = l \wedge l = \mathrm{Loc}(\iota u[\mathrm{library}'(u)],t) \wedge$
$\exists l'[\mathrm{Beg}(p) = l'] \wedge \mathrm{Agent}(e) = u \wedge u = \mathrm{mary}']$ (type <e,t>).

The predicate in (16) is still a predicate of events. To obtain a proposition asserting the existence of a particular event, we introduce the DECLARATIVE OPERATOR, which serves to existentially bind the event variable:[11]

(17) $\varnothing_{C^{\circ}} \Rightarrow \lambda Q \exists e[Q(e)]$ (type <<e,t>,t>)

(18) $\exists e \exists p[\mathrm{run}'(e) \wedge \mathrm{End}(p) = l \wedge l = \mathrm{Loc}(\iota u[\mathrm{library}'(u)],t) \wedge$
$\exists l'[\mathrm{Beg}(p) = l'] \wedge \mathrm{Agent}(e) = u \wedge u = \mathrm{mary}']$ (type t)

The proposition in (18) is the result of applying the declarative operator in (17) to the event predicate in (16). It states that there is an event of running with Mary as the Agent and that there is a path leading from an implicit starting point to the library. As a representation of what (1) means, this proposition has an obvious shortcoming, for it does not relate Mary's running to the path, and yet the two are in reality very intimately connected. Crucially, Mary traverses the path in question by running.

1.2 Finding structure in paths

The intuition that we aim to capture is that Mary runs along a path to the library in an *incremental* fashion.[12] This spatial traversal takes place in time, consequently Mary is at the implicit starting location earlier than she is at the library. However, it is not enough to say that she is at the library later than she is at the starting location, for she is also somewhere between these two locations at some intermediate time. The requirement of incremental traversal will ensure this.[13]

To address this problem, we have to elucidate further characteristics of the framework adopted. The most central of these is the hypothesis of a MEREOLOGICALLY structured universe of entities. A mereology is a PART STRUCTURE on some domain of entities, such that a given entity may or may not have parts, and if it does have parts, those parts may or may not be qualitatively similar to the entity itself. To make these points more concrete, consider the idea that the domain of paths has the structure of a mereology.

We restrict our attention to a subset of the total set of paths in a model, viz., the set of all paths to the library, i.e., $[\![$[to the library $_{\overline{\mathrm{P}}}$]$]\!]$. Any path p in this set has many PARTIAL PATHS as parts, and the combination of all of these partial paths is p.[14] Corresponding to this notion of combination is the primitive operation JOIN (⊕). If the combination of three (partial) paths p_1, p_2, p_3 is identical to p, then we write

(19) $p_1 \oplus p_2 \oplus p_3 = p.$

Note that since $\oplus$ is associative, commutative, and idempotent, the order of join is insignificant:

(20) Associativity: $(p_1 \oplus p_2) \oplus p_3 = p_1 \oplus (p_2 \oplus p_3)$
Commutativity: $p_i \oplus p_j = p_j \oplus p_i$
Idempotency: $p_i \oplus p_i = p_i$

In regard to (19), it is clear that each (partial) path p_1, p_2, p_3 is part of p. We define the PART relation ($\underline{\angle}$) in terms of $\oplus$ such that

(21) (part) $p_i \underline{\angle}\, p \leftrightarrow p_i \oplus p = p$.

In prose, p_i is part of p iff the join of p_i and p is p. It is straightforward to see that the right side of this biconditional holds by substituting $p_1 \oplus p_2 \oplus p_3$ for p and by choosing a value for the variable index 'i'.

A stronger part relation is the PROPER PART relation ($\angle$); this is defined in terms of part, with the additional stipulation that p_i is not identical to p. To wit:

(22) (proper part) $p_i \angle p \leftrightarrow p_i \underline{\angle}\, p \wedge \neg p_i = p$

Informally, p_i is a proper part of p iff p_i is part of p and not equal to p.

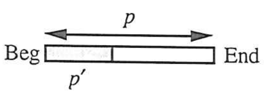
Finally, two paths may OVERLAP ($\circ$). This is trivial in the case where p_i is part of p, but not so where only a proper part of p_i is included in p. Overlap is also defined in terms of part:

(23) (overlap) $p_i \circ p \leftrightarrow \exists p_j[p_j \underline{\angle}\, p_i \wedge p_j \underline{\angle}\, p]$

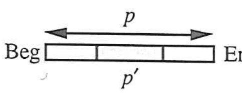
(23) says that p_i overlaps with p iff p_i and p have a partial path p_j in common.

Now that the mereological notions of join, part, and proper part have been explicated, let us return to our example of the set [[to the library $\bar{p}$]]. For any path p in this set, we ask which paths p' count as partial paths of p. The obvious answer is that any p' that is part of p is a partial path of p, as a matter of definition. Thus, p' in any of the following diagrams is a partial path of p:

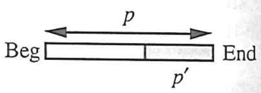
(24)



(25)



(26)



The path p' differs in each example, of course: in (24) it is an initial partial path, in (25), an intermediate partial path, and in (26), a final partial path. In all cases, p extends between a starting point and an endpoint, given by the values of the functions Beg and End, respectively.

We want to pick out a distinguished subset of the partial paths p' of p, viz., those paths p' that define an orientation for p. Consider again the set [[to the library $\bar{p}$]]; the distinguished subset contains all those partial paths of p that share the same starting point as p. The notion of INITIAL PARTIAL PATH is defined as follows:

(27) (initial partial path) $\forall p' \forall p[p' \ll p \leftrightarrow p' \underline{\angle}\, p \wedge \mathrm{Beg}(p') = \mathrm{Beg}(p)]$

In prose, (27) states that p' is an initial part of a path p iff p' is part of p and the starting point of p' is the same as the starting point of p. More technically, this means that Beg is a CONSTANT FUNCTION for any p in the relevant subset of partial paths that interests us. Note now that only in (24) does p' count as an initial partial path of p, for the starting points of p' in (25–26) are not identical to the starting point of p.

Thus far, we have considered two sets of partial paths for a given path p. The one set contains all the partial paths p' of p; the other, all the initial partial paths p' of p. Let us define these two sets as

(28) $P = \{p' : \exists p[p' \underline{\angle}\, p]\}$ and $I = \{p' : \exists p[p' \ll p]\}$,

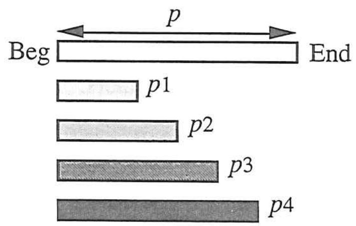
respectively. Clearly, since the notion of initial partial path is more restrictive, $I \subseteq P$. In fact, the partially ordered set $\langle I, \underline{\angle} \rangle$ has the structure of a LATTICE. To review its relevant properties, it is convenient to transform this set into an algebra with the two operations join and MEET ($\perp$). We already know join from above; meet takes two paths and yields their greatest common partial path:

(29) (meet) $\forall p \in I \forall p' \in I[p \perp p' = \iota p_i[p_i \underline{\angle}\, p \wedge p_i \underline{\angle}\, p' \wedge \forall p''[p'' \underline{\angle}\, p \wedge p'' \underline{\angle}\, p' \rightarrow p'' \underline{\angle}\, p_i]]$

Thus, the meet of p and p' is that unique path p_i which is part of both p and p' and which contains any other path p'' that is also part of both p and p'. As an illustration, consider the values of several applications of meet and join among the initial paths in (30). Keep in mind that p may have many more initial paths than illustrated here.

(30)

meet	join
$p_1 \perp p_4 = p_1$	$p_1 \oplus p_4 = p_4$
$p_2 \perp p_4 = p_2$	$p_2 \oplus p_4 = p_4$
$p_3 \perp p = p_3$	$p_3 \oplus p = p$
$p_4 \perp p = p_4$	$p_4 \oplus p = p$



The algebra $\langle I, \perp, \oplus \rangle$ is a lattice. The join of all paths p' of I is p, the MAXIMAL INDIVIDUAL of I. This is defined as follows:

(31) (maximal individual of I) $\oplus I = \iota p[p \in I \wedge \forall p' \in I[p' \underline{\angle}\, p]]$

(31) states that the maximal individual of I is the (unique) path p that contains all other p' of I as initial partial paths. This is the greatest element of I, represented by the number 1. There is also a smallest element of I, represented as the number 0, which is the MINIMAL INDIVIDUAL of I. It is the meet of all paths p' of I.

(32) (minimal individual of I) $\perp I = \iota p_0[p_0 \in I \wedge \forall p' \in I[p_0 \underline{\angle}\, p']]$

Since we assume that the set I is finite (albeit potentially large), it follows the lattice $\langle I, \perp, \oplus, 0, 1 \rangle$ is COMPLETE and BOUNDED.[15] Technically, these two properties follow from the finiteness of I. More specifically, the lattice is complete because the maximal and minimal individual of any subset of I is an element of I.

(33) $(\langle I, \perp, \oplus, 0, 1\rangle$ is complete) $\forall X \subseteq I[\oplus X \in I \wedge \perp X \in I]$

And it is bounded because the laws of 0 and 1 are satisfied:

(34) $(\langle I, \perp, \oplus, 0, 1\rangle$ is bounded) $\forall p' \in I[p' \perp 0 = 0 \wedge p' \perp 1 = p']$

By informally inspecting the diagram in (30), it is easy to convince oneself that these definitions hold (take 0 to be the null path, i.e., the path p' for which Beg(p') = End(p')).

The third and final relevant property to note is that the lattice $\langle I, \perp, \oplus, 0, 1\rangle$ is CONVEX.[16] This means that no path p' in I has gaps, i.e., every path p' in I is continuous. Again, a glance at the illustration in (30) makes it obvious that this property holds, but for the sake of explicitness I present the definition of convexity:

(35) (convexity) $p_i \not\leq p_j \not\leq p_k \rightarrow \forall p[(p_i \not\leq p \wedge p_k \not\leq p) \rightarrow p_j \not\leq p]$

A Hasse diagram for the lattice $\langle I, \perp, \oplus, 0, 1\rangle$ is shown in (36). This represents the case where I has five distinct elements. If a partial path is a proper part of another, then it is represented by a relatively lower node.

(36)

$\langle I, \perp, \oplus, 0, 1\rangle$

Although the focus of this section has been on the set I and its lattice structure, we emphasize that the full part structure of paths is not captured by this lattice. In particular, recall from (28) that I is a subset of P, hence any non-initial partial path of a given path p is simply not included in I. Importantly, the structure of the two sets differ: P has the structure of a mereology (technically: a JOIN SEMILATTICE), but I does not. This is largely because P lacks the minimal individual (cf. (32)), viz., the partial path 0 that is part of all others. A comparison of (24) with (26) confirms this: p' in (24) and p' in (26) do not overlap, hence they share no common partial path. What this means is that there is no general meet operation for the set P.

1.3 Traversal as mappings

We are nearly ready to model incremental path traversal, which is required for the semantics of (1–2). The domains of events and times both have a mereological structure, as postulated in Krifka 1989a,b. Consequently, an event can have subevents as parts, and the join operation applies to create a more complex event out of two simpler ones. The same properties hold for times. Since events occur in time, we postulate a mapping from events to times which preserves any part structure present. This is the TEMPORAL TRACE function (Krifka 1989a, 97):

(37) (temporal trace) $\forall e \forall e'[\tau(e) \oplus \tau(e') = \tau(e \oplus e')]$

Suppose that a running event has two subevents of running as parts. (37) says that the result of joining the times of each subevent is identical to the time of the join of the two subevents.

The function τ localizes events in time; however, we also need to localize events in space. For example, a motion event of running to the library is mapped into a spatial path. A function similar to the eigenplace function Loc in (11) is used for this purpose. Let as define the (partial) function Loc_p as a mapping from motion events and their temporal traces into paths:[17]

(38) (eigenplace of motion events) Loc_p: events × times → paths

Thus, the path of a running event is succinctly given by $\text{Loc}_p(\text{run}'(e),\tau(e))$.

With the functions τ and Loc_p in place, the revised translation of the VP *ran to the library* is stated as follows (cf. (14)):

(39) $\lambda e \exists p[\text{run}'(e) \wedge \text{Loc}_p(e,\tau(e)) = p \wedge \text{End}(p) = l \wedge$
$l = \text{Loc}(\iota u[\text{library}'(u)],t) \wedge \exists l'[\text{Beg}(p) = l']]$ (type <e,t>).

The predicate in (39) denotes the set of running events which are mapped (relative to their temporal trace) into some path p that extends between an implicit starting point and the library.

Path traversal is captured by endowing the eigenplace function Loc_p with two mapping properties. The first of these is a mapping from events to paths:

(40) (events to paths) $\forall e \forall e' \forall p[\text{Loc}_p(e,\tau(e)) = p \wedge e' \not\leq e \rightarrow$
$\exists p'[p' \not\leq p \wedge \text{Loc}_p(e',\tau(e')) = p']]$

In the example at hand, this mapping from events to paths means that every subevent of an event of running to the library corresponds to a partial path of the path traversed to the library. Note that (40) entails that the part structure of events is preserved in the part structure of paths. The relevant set of partial paths is P (not I), for a final subevent of running to the library is mapped into a final (and not an initial) partial path of p.

The second mapping is from initial paths to events:

(41) (initial paths to events) $\forall p \forall p' \forall e[\text{Loc}_p(e,\tau(e)) = p \wedge p' \ll p \rightarrow$
$\exists e'[e' \not\leq e \wedge \text{Loc}_p(e',\tau(e')) = p']]$

With respect to our example, (41) states that every initial partial path of the path traversed to the library corresponds to a subevent of running. Here, the initial part structure of paths is preserved in the part structure of events. The relevant partial paths belong to the subset I of P.

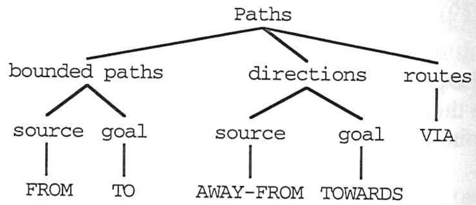
But why restrict (41) to I? That is, a mapping from paths in P to events would also be correct and would even entail the mapping property in (41). For example, the intermediate path p' of p shown in (25) should also map into a subevent e' of e. But (41) does not contradict such a mapping—it merely says nothing about it. What (41) brings out very lucidly are the 'bare essentials' of path traversal, viz., the mapping of initial paths into events. Given that the lattice structure on I is complete, bounded, and convex, the corresponding substructure on events also has these properties. Consequently, Mary fails to run to the library iff some initial partial path of p fails to map into a subevent of running.

2 Typology of paths

Ray Jackendoff, who has discussed the concept of path at length, leaves no doubt regarding his conviction that it is a 'major ontological category' and that 'it is pointless to try to eliminate it from language on the grounds of parsimony' (Jackendoff 1983, 170). I accepted this claim and proposed an analysis of *to*-paths (and by analogy, *from*-paths) in §1. But since such prepositions describe only one type of path, I now turn to the typological question of what path types play a role in natural language.

Jackendoff 1983 proposes the typology of Paths shown in (42).[18] In this classification, there are three major types: BOUNDED PATHS, DIRECTIONS, and ROUTES. The first two of these are further divided into source-paths, goal-paths, and source-directions, goal-directions, respectively.

(42) Jackendoff's (1983) typology of Paths



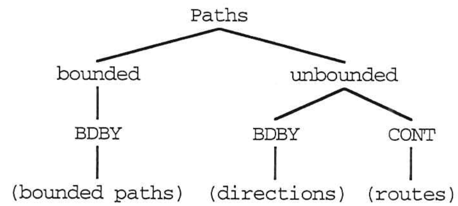
The lowest level of the typology indicates the (conceptually primitive) path-function that Jackendoff employs for each type in conceptual structure. Sentences illustrating these three major types are given in (43).

(43) a. Mary walked *to the library.* — bounded path
b. John skipped *towards the park.* — direction
c. The dog ran *along the river.* — route

The argument of a path-function is the REFERENCE LOCATION.[19] Bounded paths have endpoints: for goal-paths, as in (43a), the endpoint (designated by the argument of TO) is the location at the end of the path, viz., the library. Directions differ from bounded paths in that the reference location 'does not fall on the path, but would if the path were extended some unspecified distance' (p. 165). Thus, the park in (43b) is located in the direction but not on the path of John's skipping. Finally, routes relate the reference location to a location in the interior of the path. This means that the river in (43c) is coextensive with an interior part of the path that the dog traversed.

Concise as this typology is, we might wish to recast it so that the similarities and differences between the types are represented more perspicuously. Whereas Jackendoff 1983 treats the path-functions as conceptual primitives, Jackendoff 1991 offers an analysis of their decomposition. Paths are now understood in terms of more primitive features: they are the subset of SPACES that are 1-DIMENSIONAL and DIRECTIONAL (to be distinguished from locations, which are multidimensional and non-directional). The three major types are distinguished by virtue of the feature [±b(ounded)] and the functions BDBY ('bounded by') and CONT ('containing'), which relate the reference location to the path. This new classification is given in (44).

(44) Jackendoff's (1991) typology



There would be much to say about the interpretation of Jackendoff's features and functions (see Verkuyl and Zwarts 1992), but for present purposes it is enough to stress their intuitive motivation. A path (i.e., a 1-dimensional, directional, space) is bounded only if its two endpoints are 'in view' from the present vantage point; otherwise it is unbounded. This distinguishes bounded paths from directions and routes, which are unbounded. The function BDBY states that the reference location defines the one endpoint of the path, whether this endpoint is on the path (bounded paths) or off it (directions). Finally, CONT stipulates that the unbounded path contains the reference location (routes).

The analysis in (44) is more insightful than the one in (43) because it groups directions and routes together as a natural class against bounded paths, thereby claiming that the [±b] distinction is fundamental. The well-known aspectual test involving compatibility with time adverbials supports this division. If a PP referring to a bounded path combines with an atelic verbal predicate, the resulting VP is telic. In contrast, if a PP denoting a direction or route combines with an atelic predicate, the VP remains atelic.

(45) a. Mary walked to the library {in ten minutes, #for ten minutes}.
b. John skipped towards the park {for ten minutes, #in ten minutes}.
c. The dog ran along the river {for ten minutes, #in ten minutes}.

As shown in (45), whereas a [+b] PP brings about a telic interpretation for the VP, a [-b] PP does not change the atelic interpretation of the verbal predicate.

In Jackendoff's analysis, routes are always [-b], hence they should never behave like bounded paths. For an example like (45c), this seems correct, but other sentences tell against such a rigid correlation.[20]

(46) a. The insect crawled through the tube {for two hours, in two hours}.
b. The procession walked by the church {for 45 minutes, in 45 minutes}.
c. Mary limped across the bridge {for ten minutes, in ten minutes}.

The compatibility of the VPs in (46) with *for*-phrases occasions no problem for Jackendoff's analysis of routes. The difficulty arises when we ask why the *in*-phrases are also acceptable. If routes are essentially unbounded, as stated in (44), then it is not evident how the VPs become telic, thereby licensing the *in*-phrases.

My suggestion is that we should recognize BOUNDED ROUTES, i.e., a type of path that is fully coextensive with its reference location. The sentences in (46) all have two readings, the one in which the reference location is properly contained in an unbounded path (Jackendoff's route), the other in which the reference location coincides with the full extent of the path itself (the bounded route). In (46a), for example, the unbounded route interpretation leaves unclear where the insect began and completed its crawl. It may have been outside or inside the tube; we simply do not know. This is the acceptable reading with the *for*-phrase. The bounded route interpretation, in contrast, entails that the path of traversal began at the one end of the tube and was completed at the other end. This yields the telicity necessary for the *in*-phrase. Analogous considerations apply to (46b,c).

Descriptions of bounded routes are clearly not equivalent to those of bounded paths. Although both types of paths are bounded, with bounded routes the reference location is coextensive with the whole path, whereas with bounded paths the reference location merely defines the one endpoint of the path. Note, for example, that crawling through the tube in two hours can be quite different from crawling to the end of the tube in two hours, for the starting points need not be the same. Nonetheless, what bounded routes and bounded paths have in common is that they have starting points and endpoints, whether implicit or explicit.

Both endpoints are made explicit in the following examples:

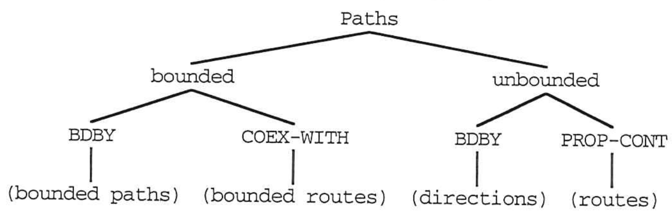
(47) a. The insect crawled from one end of the tube through it to the other end {in two hours, #for two hours}.
b. Mary walked from the student union through the tunnel to the library in {ten minutes, #for ten minutes}.

By stating the endpoints of the bounded route in (47a), we rule out the unbounded route interpretation. A bounded path is imputed in (47b), of which the location of the student union is the starting point, and the location of the library, the endpoint. The (inside of the) tunnel defines part of the course traversed; it is probably not coextensive with the whole path, hence *through the tunnel* here actually describes an unbounded route, which is embedded within the description of a bounded path. This is clear if we ignore the endpoints, as is done in a continuation of (47b):

(48) Mary walked from the student union through the dark tunnel to the library in ten minutes. She walked through the scary tunnel for only three (of the ten) minutes.

If there are bounded routes, as I maintain, then the typology of paths needs to be recast to reflect this. Specifically, the disparity obvious in (44) disappears in the new typology, shown in (49). Routes now appear in both sides of the [±b] division.

(49) (Near) Symmetric typology of paths



Even if we try to preserve as much of Jackendoff's conception as possible, it proves difficult to keep his CONT function without any modification. I have changed it to PROP-CONT ('properly containing') and added COEX-WITH

('coextensive with'): whereas unbounded routes properly contain their reference location, bounded routes are coextensive with their reference location.

Further evidence for the distinction between unbounded and bounded routes comes from the behavior of PREVERBS in Hungarian. Preverbs are adverbs or postpositions that appear immediately before the verb in neutral (i.e., non-contrastive) sentences.[21]

(50) a. Kati tíz perc-en keresztül sétált a híd-on át.
Kati ten minute-on through strolled the bridge-on across
'Kati strolled across the bridge for ten minutes'
b. Kati tíz perc alatt *át*-sétált a híd-on.
Kati ten minute under across-strolled the bridge
'Kati strolled across the bridge in ten minutes'

(51) a. A diákok húsz perc-ig mentek el a templom mellett.
the students twenty minute-to went forth the church by
'The students went past the church for twenty minutes'
b. A diákok húsz perc alatt *el*-mentek a templom mellett.
the students twenty minute under forth-went the church by
'The students went past the church in twenty minutes'

(52) a. Éva négy nap-on keresztül épített a fák körül.
Eve four day-on through built the trees around
'Eve built around the trees for four days'
b. Éva négy nap alatt *körül*-építette a fák-at.
Eve four day under around-built the trees-ACC
'Eve built around (= enclosed) the trees in four days'

The pairs in (50–52) contrast a sentence lacking a preverb with a very similar sentence containing one. The first sentence of each pair describes an atelic event, as is evidenced by the choice of time adverbial. Indeed, only the durative adverbial and not the time-span adverbial is acceptable on a neutral interpretation of the sentence if a preverb is missing. Compare this with the second sentence of each pair, in which the presence of a preverb induces a telic reading for the VP.[22]

The crucial point is this: whereas the PostPs in (50a), (51a), and (52a) describe unbounded routes, the preverbs in (50b), (51b), and (52b) introduce bounded routes circumscribed by the verb's complement. In (50a), for example, we understand that Kati strolled across the bridge for ten minutes, but we do not know where she started or ended. This is not so in (50b): here we know that the starting point was immediately before the bridge, and the endpoint, immediately after it. This difference in meaning between the two sentences is concisely stated in terms of the distinction between unbounded and bounded routes, but it is obscured if this distinction is not available. Similar reasoning applies to the pairs in (51–52).

3 Partitivity and Paths

In Jackendoff's typology, directions stand out because the reference location falls not on the path, but rather at some unspecified distance from it in the same direction. Thus, although directions are essentially unbounded, they are still bounded by the reference location at some (distant) point. Verkuyl and Zwarts (1992, 498) put the matter somewhat differently: a path function like '[$_{Path}$ TOWARD ([STORE])] denotes a part of the path P_{TO} that has no fixed end point.' Although Verkuyl and Zwarts do not provide an explicit representation for *toward(s)*, I believe that their intuition about a *towards*-path being part of a *to*-path is essentially correct (and more lucid than Jackendoff's formulation).[23]

With a view to revising the typology in (49), let me propose that the [±b] distinction be recast in terms of maximal paths ([+b]) vs. partial paths ([–b]). In other words, directions are partitives of bounded paths. Specifically, the preposition *towards* denotes a relation between initial partial paths of some path and locations (cf. (12)):

(53) $towards \Rightarrow \lambda l \lambda p' \exists p[p' \ll p \wedge \text{End}(p) = l \wedge \exists l'[\text{Beg}(p) = l']]$

If we apply this formula to a location, we get a predicate of initial partial paths:

(54) [towards the library $_{\overline{P}}$] $\Rightarrow$
$\lambda l \lambda p' \exists p[p' \ll p \wedge \text{End}(p) = l \wedge \exists l'[\text{Beg}(p) = l']](\text{Loc}(\iota u[\text{library}'(u)],t)) \rightarrow$
$\lambda p' \exists p[p' \ll p \wedge \text{End}(p) = l \wedge l = \text{Loc}(\iota u[\text{library}'(u)],t) \wedge \exists l'[\text{Beg}(p) = l']]$

The expression in (54) denotes the set of initial partial paths of a path p that extends between an implicit starting point and the location of the library.

Compare the translation of *towards the library* in (54) with that of *to the library* in (12). Whereas the former has the property of DIVISIVE REFERENCE, the latter does not. Divisive reference[24] for paths is defined as

(55) (Q has divisive reference) $\forall p \forall p'[Q(p) \wedge p' \ll p \rightarrow Q(p')]$.

A predicate Q has divisive reference only if for any path p that it applies to, it also applies to all initial partial paths p' of p. The predicate in (54) clearly has divisive reference, for any initial partial path p'' of an initial partial path p' of a path p is evidently also an initial partial path of p. Thus, any initial partial path of a path towards the library is also a path towards the library. This contrasts with the predicate in (12), which clearly lacks divisive reference: any initial partial path of a path to the library is clearly not a path to the library.

Temporal adverbials are sensitive to the property of divisive reference (cf. (45)). In particular, durative adverbials like *for ten minutes* require the VP to have divisive reference, which accounts for their incompatibility with VPs containing *to*-phrases.[25] Time-span adverbials like *in ten minutes*, however, do not combine with VPs having divisive reference, hence their unacceptability with VPs containing *towards*-phrases.[26]

Further motivation for restricting reference to initial partial paths in (53–54) comes from measure phrases. Consider the following contrast:

(56) a. Mary ran 100 meters towards the library.
b. Mary ran 100 meters to the library.

The meaning of (56a) is that Mary traverses a path measuring 100 meters that is an initial partial path of a path to the library, i.e., the starting point of Mary's path coincides with the starting point of a path to the library, but the endpoint does not. Significantly, Mary does not traverse just any partial path measuring 100 meters—it is necessarily an initial partial path. In (56b), the length of the path to the library that Mary traverses is 100 meters.

If we analyze such measure phrases as $\overline{P}$ adjuncts, then reasonable translations of the $\overline{P}$s in (56) are as follows (cf. (54), (12)):

(57) [100 meters [towards the library $_{\overline{P}}$] $_{\overline{P}}$] $\Rightarrow$
$\lambda p' \exists p[p' \ll p \wedge \text{End}(p) = l \wedge l = \text{Loc}(\iota u[\text{library}'(u)],t) \wedge$
$\exists l'[\text{Beg}(p) = l'] \wedge \text{meter}'(p') = 100]$

(58) [100 meters [to the library $_{\overline{P}}$] $_{\overline{P}}$] $\Rightarrow$
$\lambda p[\text{End}(p) = l \wedge l = \text{Loc}(\iota u[\text{library}'(u)],t) \wedge \exists l'[\text{Beg}(p) = l'] \wedge$
$\text{meter}'(p') = 100]$

In (57–58), meter′ is treated as a measure function on paths whose range is the positive real numbers. The formula in (57) is a predicate of paths measuring 100 meters which are initial partial paths of a path to the library, and the one in (58) is simply a predicate of paths to the library that measure 100 meters. These representations capture our intuitions about the sentences in (56).[27]

Not all measure phrases behave alike, however. The paradigm in (59) exhibits measure phrases that resist combination with *towards*-phrases.

(59) a. Mary ran halfway {to the library, #towards the library}.
b. Mary ran partway {to the library, #towards the library}.
c. Mary ran all the way {to the library, #towards the library}.
d. Mary ran most of the way {to the library, #towards the library}.
e. Mary ran none of the way {to the library, #towards the library}.

One way to account for the contrast between (56) and (59) is to claim that the measure phrases in (59) impose a uniqueness requirement on the path of which they measure an initial partial path. For example, *halfway* translates as a predicate of initial partial paths whose measure is precisely half of the measure of the greatest path that contains them:

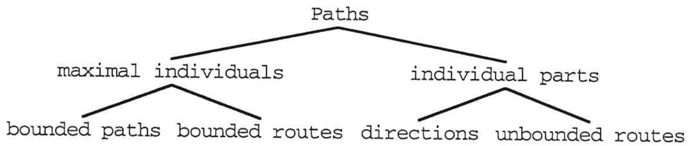
(60) $halfway \Rightarrow \lambda Q \lambda p \exists p'[Q(p') \wedge p \ll p' \wedge \mu(p) = \mu(p') - \mu(p) \wedge$
$\forall p''[p' \ll p'' \rightarrow p' = p'']]$

In prose, the formula in (60) denotes the set of initial partial paths p whose measure is identical to the result of subtracting their measure from the measure of some unique path p' that contains p. More concisely, *halfway* measures a path p only with respect to the maximal individual path p' of which p is an initial partial path. The other measure phrases in (59) would be treated similarly.

Although details remain to be elucidated, (60) yields the contrast noted in (59a), for *to*-paths are maximal individuals, but *towards*-paths—as initial partial paths of a maximal individual—are not. Specifically, the proposition expressed in the final conjunct of (60) fails to hold with *towards*-paths, for initial partial paths are not unique, and therefore the *towards*-phrase in (59a) is unacceptable.

In sum, analyzing *towards* as a partitive of *to* is a telling option. The obvious next step would be to extend this analysis to account for the distinction between bounded and unbounded routes. On this view, bounded routes would also be maximal individuals, and unbounded routes, their parts. The new typology is presented in (61), which should be seen as a mereological (re)interpretation of the typology in (49). If correct, then we have also garnered strong support for the thesis that the domain of paths has a mereological structure.

(61) Mereological typology of Paths



Notes

[0]I am grateful to Paul Kiparsky, Peter Sells, Henriëtte de Swart, Elizabeth Traugott, and especially to Stanley Peters and Alessandro Zucchi for fruitful discussion concerning (parts of) the material in this paper. All shortcomings are mine.

[1]Jackendoff 1983 uses the brackets #·# for references to projected-world entities.

[2]Jackendoff's postulation of a rich conceptual ontology parallels the postulation of richer model structures in formal semantic treatments, as is witnessed in works like Bach 1986, Krifka 1989a,b, Link 1983, Ojeda 1993, and Parsons 1990.

[3]The analysis to be presented is mine. I take the liberty and risk of recasting Jackendoff's basic intuition that PPs make reference to paths, and I develop it further as present purposes demand. My account shares certain similarities with the approach taken by Bierwisch 1988.

[4]Q, Q' are predicate variables of type <e,t>, and e, e' are sorted variables for events.

[5]In the literature on prepositions, a variety of analyses have been proposed. For some recent proposals, see Bierwisch 1988, Klein 1991, Wunderlich (1991, 1993), and Zwarts 1992.

[6]In algebraic approaches, definite descriptions are analyzed as referring to supremum individuals in a lattice sort of objects (see Krifka 1989b for such a treatment). Since nothing hinges on this point, I adhere to the traditional (Russellian) analysis. Note that the iota operator has type <<e,t>,e>.

[7]Klein (1991, 83), in an analysis of static prepositions, emphasizes that only locations of objects (and not objects themselves) stand in spatial relations to each other. I take this to hold for the analysis of dynamic prepositions as well, *pace* Jackendoff 1983.

[8]I borrow the term EIGENPLACE from Wunderlich 1993, a translation of Klein's (1991) term EIGENORT. Krifka (1989b, 200) presents what he calls the LOKALISIERUNGSFUNKTION.

[9]The sorted variables t, t', etc. stand for intervals or points of time. Since Loc is a function, it automatically follows that an object cannot occupy two locations at a single time.

[10]That is, the translation of *from* is $\lambda l\lambda p[\mathrm{Beg}(p) = l \wedge \exists l'[\mathrm{End}(p) = l']]$. Ultimately, it may be preferable to analyze l' as a free variable that receives its value contextually, but I do not consider this option here.

[11]This operator is presented in Krifka (1989a, 90). We can assume that it resides in C°.

[12]See Dowty 1991 for the related notion of Incremental Theme.

[13]To my knowledge, Verkuyl and Zwarts 1992 is the most explicit attempt at a set-theoretic modeling of path traversal in a formal semantic framework.

[14]I prefer the term PARTIAL PATH to PATH-PART for its euphony. Keep in mind, however, that its use in this paper is technical.

[15]For these and other lattice-theoretic notions, see Landman (1991, chap. 6).

[16]This follows from the fact that our lattice is a FILTER. For filters, see Landman 1991.

[17]Actually, if paths are defined in terms of locations, it is feasible to unify Loc_p with the function Loc in (11). However, it is beyond the scope of this paper to reconstruct paths in terms of a mereology of locations.

[18]Henceforth, (capitalized) 'Path' is used to designate the superordinate category.

[19]Jackendoff (1983, 161) also appeals to a REFERENCE OBJECT, which we ignore. See fn. 7 above.

[20](46a,b) are adapted from Declerck (1979, 768), who makes a different point.

[21]These sentences should be interpreted without focus. Note that *el* in (51a) is a PostP adjunct and not a postposed preverb, i.e., *el* forms a constituent with the following PostP.

[22]My semantic observation about these examples is quite independent of their syntactic analysis. This is not the place to discuss the (dis)advantages of head movement for Hungarian.

[23]I do find their claim of 'no fixed end point' puzzling, however.

[24]In (55), I slightly modify Krifka's (1989a, 78) definition of divisive reference.

[25]If Moltmann's (1991) general analysis of durative adverbials as part quantifiers is adopted, then the requirement that the VP have divisive reference follows automatically.

[26]Obviously, more should be said about the mechanism of aspectual composition here. The basic idea is that the VP inherits the aspectual properties of the verb's complement. Thus, if the PP has (lacks) divisive reference, then the VP also does.

[27]Note that the predicate in (57) no longer has divisive reference. This is expected, as an initial partial path of a path measuring 100 meters does not itself measure 100 meters. Observe the contrast between *Mary ran 100 meters towards the library in 45 seconds* and *#Mary ran 100 meters towards the library for 45 seconds* (cf. (45)).

References

Bach, Emmon. 1986. The algebra of events. *Linguistics and Philosophy* 9: 5–16.
Bierwisch, Manfred. 1988. On the grammar of local prepositions. *Syntax, Semantik und Lexikon, Studia Grammatica* 29: 1–65.
Declerck, Renaat. 1979. Aspect and the bounded/unbounded (telic/atelic) distinction. *Linguistics* 17: 761–794.
Dowty, David. 1991. Thematic proto-roles and argument selection. *Language* 67: 547–619.
Jackendoff, Ray. 1983. *Semantics and cognition*. Cambridge: The MIT Press.
———. 1990. *Semantic structures*. Cambridge: The MIT Press.
———. 1991. Parts and boundaries. *Cognition* 41: 9–45.
Klein, Wolfgang. 1991. Raumausdrücke. *Linguistische Berichte* 132: 77–114.
Krifka, Manfred. 1989a. Nominal reference, temporal constitution, and quantification in event semantics. *Semantics and contextual expression*, ed. by R. Bartsch, J. van Benthem, and P. van Emde Boas, 75–115. Dordrecht: Foris Publications.
———. 1989b. *Nominalreferenz und Zeitkonstitution: zur Semantik von Massentermen, Pluraltermen und Aspektklassen*. München: Wilhelm Fink Verlag.
Landman, Fred. 1991. *Structures for semantics*. Dordrecht: Kluwer Academic Publishers.
Link, Godehard. 1983. The logical analysis of plurals and mass terms: a lattice-theoretical approach. *Meaning, use, and interpretation of language*, ed. by R. Bäuerle, C. Schwarze, and A. von Stechow, 302–323. Berlin: Mouton.
Moltmann, Friederike. 1991. Measure adverbials. *Linguistics and Philosophy* 14: 629–660.
Ojeda, Almerindo. 1993. *Linguistic individuals*. Stanford: CSLI.
Parsons, Terence. 1990. *Events in the semantics of English: a study in subatomic semantics*. Cambridge: The MIT Press.
Verkuyl, Henk, and Joost Zwarts. 1992. Time and space in conceptual and logical semantics: the notion of Path. *Linguistics* 30: 483–511.
Wunderlich, Dieter. 1991. How do prepositional phrases fit into compositional syntax and semantics? *Linguistics* 29: 591–621.
———. 1993. On German *um*: semantic and conceptual aspects. *Linguistics* 31: 111–133.
Zwarts, Joost. 1992. *X′-syntax–X′-semantics: on the interpretation of functional and lexical heads*. Ph.D. dissertation, Utrecht University.