Paths and the Language of Change

Jean Mark Gawron
San Diego State University

September 2, 2007

1 Introduction

[1]

Consider the sentences in (1):

(1) a. The fog extended (from the pier to the point).
b. The crack widened (from the north tower to the gate.)
c. The storm front zigzagged (through the entire state of Colorado)
d. Snow covered the mountain (from the valley floor to the summit).

Sentences like (1a)-(1d) have attracted the attention of a number of authors (Jackendoff 1990, Matsumoto 1996, Talmy 1996, Gawron 2005). Each has both an event reading and a stative reading. For example, on what I'll call the *event reading* of sentence (1a), a body of fog beginning in the vicinity of the pier moves pointwards, and on the other, stative reading, which I'll call an *extent* reading, the mass of fog sits over the entire region between pier and point. The event reading entails movement. The extent reading entails extension, the occupation of a region of space. Similarly, there is a reading of (1b) describing a crack-widening event, as well as a reading describing the dimensions of the crack, increasing in width along an axis extending from the north tower to the gate; and readings of (c) and (d) describing movement events as well as readings describing the configuration of the storm front and the snow respectively.

[1] I am grateful to Farrell Ackerman, Chris Barker, Daniel Buring, Andy Kehler, and Rob Malouf for saying interesting things, sharing insights, asking good questions, and pointing out boners. This work also benefited from the questions and comments of audiences at UCSD and SALT who heard talks on early versions. Any remaining flaws are due to my own shortcomings.

Building on the analysis of Hay et al. (1999), Gawron (2005) proposes an event-based analysis of the first 3 cases assuming the lexical semantics of each predicate defines a *state function*, f. Values of f define the start and end states of an event e and the differences between these values the amount of change in e. In the case of *widen* f is a function to degrees, and in the case of *extend*, a function to spatial regions. The distinction between event and extent readings depends on whether the domain of the function is the time axis (event reading) or some contextually provided spatial axis (extent readings). Call this the GHKL analysis. The central claim of the GHKL analysis is that extent readings describe change with respect to an interval of space, while event readings describe change with respect to an interval of time. That is, while uncontroversially stative, extent readings still describe change. As a consequence, there are both spatial accomplishments (2a) and spatial activities (2b):

(2) a. The crack widened nearly half an inch in ten meters.
    b. The crack widened for 100 yards.

The frequent appearance of path-phrase modifiers on both readings, noted by Jackendoff (1990), is because path-phrase modifiers are key linguistic devices for defining and orienting spatial axes.

An important feature of this analysis is that it is **aspectually neutral**. That is, the difference between extent and event readings is not a difference of aspectual nature, as in Jackendoff (1990), which derives accomplishment or achievement event readings from stative extent readings by means of a BECOME operator. Rather, on the GHKL analysis, both readings involve change, and the only difference between them is whether the domain of change is spatial or temporal.

This paper seeks to revise and extend the GHKL analysis and to draw out more carefully some consequences for a general characterization of change, or difference between states and non-states. I will first argue that in the general case an aspectually neutral analysis is inadequate. Extent readings have varying aspectual natures. Some describe change and some do not. In particular, I will argue that the extent reading of (1d) describes a spatial state. Making this argument will require looking at some new data. Explaining this data will lead to a more careful examination of the structure of state functions, the primary vehicle for describing change in the GHKL analysis. That will open the door for an attempt to axiomatically characterize state functions and finally to some speculations as to the utility of employing state functions to classify all verb meanings.

The argument that extent readings are aspectually diverse is straightforward. First, in contrast to event *cover*, there is no evidence that extent *cover* is a spatial accomplishment or activity:

(3) a. # The snow covered 100 square miles of canyon in just 5 miles.
b. The snow covered the canyon in 5 minutes.

Second, there is the incompatibility of extent *cover* with aspectual adverbs like *gradually*. Extent predicates may be classified as either + or - Grad based on whether they are compatible with *gradually*:

(4) Graduality

[- Grad$_X$]	(a)	The fog gradually covered the peninsula
	(b)	The fog gradually extended to the point.
[+ Grad$_X$]	(c)	The crack gradually widened from the tower on.
	(d)	The storm front gradually zigzagged to the border.

All the predicates in (4) are compatible with the adverb *gradually* on at least one reading. The sentences marked [- Grad$_X$] have only event readings; sentences marked [+ Grad$_X$] have both event and extent readings.

Given the structure of the GHKL analysis, it is fairly significant that there are cases in which *gradually* is compatible with event readings but not the corresponding extent readings. Assume an account of *gradually* like that of Pinon (2000): graduality minimally requires that a degreeable state function be increasing.[2] If the only difference between an event reading and a state reading is the domain of the state function, why can the state function increase in one case and not in the other? I will argue that in the case of *cover* and *extend*, an aspectually neutral analysis is impossible. Extent *cover* and *extend* are "spatial states"; event *cover* and *extend* are accomplishments.[3] Let us call this array of adverbial modification facts in (4), distinguishing *extend* and *cover*, **graduality facts**.

---

[2] Pinon requires more than this, but this weaker assumption suffices for present purposes.

[3] A similar pattern emerges when we look at the degree modifying adverbs like *sharply*:

(5) a. The road widened sharply.
b. The road zigzagged sharply.
c. # The shadows covered the patio sharply.
d. # The shadows extended sharply.

There is considerable variability in choice for degree adverbs. Thus, beside *widen* and *zigzag sharply*, we have *cool # sharply/considerably/a little/a lot rose/fell sharply/considerably/a little/a lot*. But trying these alternatives with *cover* and *extend* we have:

(i) # The shadows covered the patio considerably/a lot.
(ii) ? The shadows covered the patio a little.

One might be tempted to try to explain the the graduality facts in (4) simply by saying that *gradually* requires state functions with degree ranges (and say both *cover* and *extend* have mereological ranges), but this does not account for the fact that both *cover* and *extend do* combine with *gradually* on the event reading. I will argue that the relevant constraint on *gradually* is that it requires change. Thus, *gradually* is compatible with mereological state functions. The problem with the extent readings of (4a) and (4b) is that they are spatial states, and there is no change at all.

Summarizing: Accounting for differences in aspectual nature leads to several kinds of differences among extent predicates. First, some will be spatial accomplishments and activities; others will be spatial states. Second, even among spatial accomplishments/activities, some will incorporate the INCREASE operator into their definitions, and some will not. Third, some extent predicates are *basic* spatial path predicates, and will continue to exploit spatial paths even on event readings. This will lead me to hypothesize two kinds of temporally indexed paths *incremental* ND *non-incremental*. Fourth some state functions will returns paths, and some will return paths or locations Thus with regard to lexical aspect, this account will be a mixed degree-based and mereological account.

Having accounted for the basic aspectual variation, I will turn to the general characterization of the stative and nonstative distinction that emerges. A crucial feature of the account is that axes of change may be added to predicates, through the use of an INCREASE operator, which will require a state function with

---

(5a) uses two adverbials that never work with positive adjectives (# considerably tall/bright/heavy), only comparative adjectives (considerably taller/brighter/heavier), and these are out, though they are okay with other degree achievement verbs. A speculation about the source of this correlation of verbal modifers with comparative modifiers is that the modifiers distinguish between intervals on a degree scale and points on a degree scale. Positive adjectives identify points, not intervals, on a scale, while comparative modifiers identify the size of differences on the degree scale (*a lot taller* means the difference between two heights, neither of which needs to be above the tallness standard, is great). Because of something like the INCREASE operator used in the derivation of degree achievements, the verbal degrees being modified are also differences or intervals on the degree scale. (5b) seems improved, but *a little* is a modifier of positive adjectives as well as comparatives (*a little warm, a little bright*). It is also notable that a *a little* is a mass modifier (*a little wine*). I will argue below that the range of the *cover* state function is a mereological parts domain (spatial regions) rather than a scale, so this may be a factor for the favoring of a *a little* with *cover*. In any case, the occurrence of this more general modifier *a little* does not seem to be any indicator of a measure of *change*. The facts with *extend* are simpler. No degree modication at all is possible as long as limit ourselves to extent readings:

(iii) # The shadows extended considerably/a lot/a little. (extent reading) a range obeying something called the Remainder Axiom, definable with state and end state properties obeying something called **path cumulativity**. A somewhat revised notion of stative property can now be recovered through the notion of path cumulativity. There is a fairly natural generalization of path that allows this to be generalized to all states.

I will also argue that these data show there is no general decomposition of non-stative predicates, even degreeable non-stative predicates, via some kind of aspect-changing operator like BECOME or INCREASE. In particular, the predicate *zigzag*, and a related set of **path-shape predicates**, while clearly degreeables predicate of change, do not decompose into either.

2 Basic analysis

In this section I try to more precisely define the verbs exhibiting an event/extent ambiguity, precisely define what ity means to use a spatial axis and as an axis of change, and propose an analysis of path phrases that shows how path phrases exploit and constrain contextually provided spatial axes.

2.1 The verb classes

The verbs in (1) are examples of a large class of verbs exhibiting event/extent ambiguities. These verbs include EXTENT verbs discussed in (Jackendoff 1990), for example *cover*, *fill*, *dot*, *envelope*, *surround*, *span* and *extend*. Some examples are shown in (6):

(6) a. Water filled the pool.
b. Mist enveloped the tent
c. Soldiers surrounded the compound
d. Boulders littered the valley floor.

Included among extent predicates is a class that either lack event readings or accept them only very reluctantly:

(7) a. Plastic shampoo bottles cluttered the single shelf in the cramped shower.
b. The bridge spanned a rocky canyon.
c. Antelope dotted the hillside.

There is a class of examples for which it is difficult to distinguish two readings, but also difficult to say whether the reading is an event reading or an extent reading:

(8) Smoke columned above the small chimney.

Does this describe the columnar shape the smoke makes against the sky or the process by which the smoke outline stacks above the chimney? Here I would say that the ambiguity is part of the effect the sentence achieves.

Also included among extent predicates are the verbs called *path-shape* verbs in FrameNet (Fillmore and Baker 2000), listed in (9):[4]

(9) angle, bear, bend, climb, crest, crisscross, cross, curl, descend, dip, dive, drop, edge, emerge, enter, exit, leave, meander, mount, plummet, reach, rise, round, skirt, slant, snake, swerve, swing, traverse, undulate, veer, weave, wind, zigzag

As the name suggests, the unifying semantic characteristic of path-shape verbs is that they specify the shape of a path. Either the shape is the configuration of the theme in space or the theme is moving and the verb specifies the shape of the path of motion:

(10) a. The road zigzagged up the hill. [Extent reading]
b. The halfback zigzagged to the goal line. [Event reading]

Criterial for the class is that, on extent readings, they allow inanimate paths that are extended in space in the required configuration. This distinguishes them from manner of motion verbs. Repeating some examples of from FrameNet:

(11) a. The road snaked up the hill . [path-shape]
b. # The road slithered up the hill. [manner of motion]

I will use the term **extent predicates** for all path-shape verbs and all the verbs from Jackendoff's list, except *cover* and *fill*.

Although it appears at first as if the change in selection restrictions between event and extent readings for path-shape verbs must be handled by some sense transfer rule, I will argue that a single sense applies in both event and extent readings. The semantic constancy of path-shape verbs is captured by the class-name: in both event and extent uses each path shape predicate ascribes a

[4]To this list I would add the verb *column* illustrated in (8). Note that some rather natural candidates, such as *circle*, are missing, presumably because it was difficult to find clear cases of extent readings:

(i) ? A group of wooden posts circled the dirt portion of the barn yard.

particular shape to a path. On the event reading that is the shape of a path traced out in time, on the extent reading it is the shape of a path realized by a static spatial configuration. Thus, with respect to extent readings, what is going on here is fundamentally the same as what is going on with extent predicates like *extend*. The figure in an extent reading is always represented as *extended* over the entire path, and the property being attributed is always a spatial configuration of the figure's parts. It follows that figures that cannot be extended in the required configuration (such as halfbacks) are disallowed.

The remaining question is why verbs like *zigzag* allow non-extended figures like halfbacks on their event readings. Putting this another way: What distinguishes verbs like *zigzag*, which allow non-extended figures, from verbs like *extend* which do not? Most motion verbs depict *displacement*, advancement to a new location accompanied by removal from an old one, allowing rigid figures like halfbacks. On this analysis, it is a natural consequence of the way paths are defined that temporally indexed paths will describe displacement and spatially indexed paths will describe extent. But it is an idiosyncratic property of verbs like *extend* and *surround* that they describe what I will call *spreading movement*: as location $i + 1$ is occupied location i continues to be occupied. Thus rigid figures like halfbacks are disallowed. Formally spreading motion will be captured in Section 3.2 by means of the INCREASE operator.

There are two other classes of verbs in FrameNet that contain verbs of interest, and a third that contains verbs with only extent readings. In (12), adjectives have been omitted from frames mixing verbs and adjectives[5] and the verbs showing extent and event readings are italicized:

(12) a. **Adorning frame**: adorn.v, *blanket.v*, *cloak.v*, *coat.v*, *cover.v*, deck.v, decorate.v, dot.v, dress.v, *encircle.v*, *encrust.v*, *envelop.v*, festoon.v, *fill.v*, film.v, garnish.v, line.v, pave.v, stud.v, *wreathe.v*

b. **Abounding-with frame**: crawl.v, teem.v, throng.v

c. **mass-motion frame**: crowd.v, flock.v, flood.v, hail.v, parade.v, pelt.v, *pour.v*, rain.v, roll.v, shower.v, *stream.v*, swarm.v, teem.v, throng.v, troop.v

The *adorning* frame splits between verbs with extent readings only, and a subset of *cover*-like veerbs and verbs involving circular configuration or containment that show both readings. The *abounding-with* frame contains only extent verbs, and

[5]This is why the closely related *lively-place* frame, which contains only adjectives like *busy*, *frenetic* and *abuzz*, has been left out.

the *mass motion* frame contains mostly verbs with event readings only, excepting cases like:

(13) Light poured/streamed through the window.

In the discussion in this paper, I will at the the risk of some confusion, refer to all of the verbs from all 4 frames (*path-shape*, *adorning*, *abounding-with*, and *mass-motion*) as path-shape verbs, since the distinctions among the frames will not play a role in the analysis.

Another class of verbs that show event/extent ambiguities is a large class of degree-achievement verbs, including *narrow, warm, cool, rise, fall, darken, lengthen, lighten, shorten, brighten, dim, grow, smooth, thicken, swell, shrink, bleach*, and all color degree achievements. I will call these **extent degree achievements**. All of these verbs share the property that they are degreeable like the degreeable states they are related to, and in some cases the degree argument may be overtly filled by a measure phrase:

(14) a. The river widened 10 feet.
b. The river widens more than the road.

At first blush it might appear that *lengthen*, in contrast to *widen*, does not allow extent readings, on the basis of contrasts like the following:

(15) a. The cable widened in the den.
b. The cable lengthened in the den.

Sentence (15a) has an extent reading: "The portion of the cable in the den was wider than elsewhere." In contrast, though (15b) has a perfectly good though unlikely event reading, it has no extent reading. It cannot mean: "The portion of the cable in the den was longer than elsewhere."

But examples with *lengthen* are possible if the correct choice of *theme* is made, that is, if we are looking at the kind of object whose length can vary along the axis implied by the path phrase:[6]

(16) The dress lengthened in back.

In fact, the contrast between cables and dresses and how their lengths are measured provides an important clue as to how extent readings with scalar predicates work. Example (16) works because the path phrase *in back* defines a front to back

[6]Thanks to Daniel Buring for this illuminating example.

axis along which the lengths of successive axial sections of the dress increase. The only axis available for (15) is an axis that defines successive cross sections of the cable, and the contrast between (15a) and (15b) is due to the fact that cable cross-sections conventionally have widths but not lengths. This example provides the key concept connecting extent readings and paths: the idea of an axis. Extent readings assert properties extended along a spatial axis, describable by a path.

This idea is elaborated in the next section.

Note that a subset of path-shape verbs might also be analyzed as degree-achievements, including *descend, fall, drop, plummet, dive, raise, climb,* and *mount*. It is an interesting property of the analysis proposed here that these can be (and I will argue in Section 5, should be) analyzed as degree achievements while still predicting the change in selection restrictions between event and extent readings.

Finally, although the analysis to be defended here posits aspectual variety within extent predicates it needs to be acknowledged that there are also some gaps. For example, on the account to be defended, there are verbs that alternate between temporal state and temporal accomplishment (*fill* and *cover*, for example):

(17) The snow filled/covered the meadow.[claim: This is ambiguous between a temporal state and temporal accomplishment reading.]

There are still more temporal accomplishment verbs with morphologically related adjectives expressing semantically related temporal states (all the aforementioned degree achievement pairs like *wide* and *widen*):

(18) a. The river was 10 feet wide.
b. The river widened 10 feet.

However, there are a number of extent verbs and extent adjectives to be classified as spatial states, where it is unclear what a related spatial accomplishment would even *mean*. For example, *teem* is a spatial state, on the basis of the cumulativity criterion to be defined in Section 3.3. This will require that (a) and (b) entail (c):

(19) a. The waters of the bay teemed with fish from point A to point B.
b. The waters of the bay teemed with fish from point B to point C.
c. The waters of the bay teemed with fish from point A to point C.

Given that (19a) and (19b) are states, this cumulative path inference establishes them as spatial states. What would the correspond spatially telic property be?[7] There seems to be none. In Section 5 we try to explin why not.

[7]The answer is not BECOME(teeming), because that would be a temporal accomplishment. The spatially analogous operator meaning *go from not-teeming* to *teeming* as we move along some spa-

2.2 The basic analysis: Spatial axes

In this section, I argue that the first assumption required in order to account for extent readings is that there is such a thing as change with respect to space, and what is required to make sense of that is the concept of a *spatial axis*, an ordered set of collinear points that can serve as an *axis of change*. I further argue further that such axes that are independently motivated for the language of space, and they interact with extent readings in just the way expected if they are axes of change.

My starting assumption is that descriptions of change require two ordered sets. Consider (20)

(20) The boiling point of water drops 3 degrees Fahrenheit between sea level and 4000 feet.

The point of this example is that it describes a change that is independent of time: a functional dependence between altitude and boiling point. Informally: as the altitude increases the boiling point falls. But in order for that description to make sense, altitude has to be something that can increase and boiling points something that can fall. Functional change is the existence of some correlation between two ordered domains, and change with respect to time is a special case of that.

Treating change with respect to space as another case of functional change thus raises the following issue:

In what sense can space be thought of as an ordered domain?

An obvious answer is to organize space by means of axes, as we do with Cartesian coordinate systems. This is not the only possibility but it has the attraction of simplicity. The first step in accounting for change with respect to space, then, would be the addition to the semantics of an *axis of change*, informally defined and exemplified in (21):

(21) a. **An axis** is a set of elements with a well-ordering.
b. The Fahrenheit scale is an axis, and in (20) it is used as an axis of change to measure change in boiling points.
c. A line parallel to the face of the wall is the axis of change in (1b).

tial axis does not seem to work either. It is hard to know what such an accomplishment predication would say that (19a) does not already say or implicate. Finally, this paper does not use BECOME, adopting the HKL analysis on which all the work done by BECOME in previous analyses is handled by the operator INCREASE. We will argue in Section 5 that that still leaves a class of spatial states like *teem* and spatial accomplishments like *zigzag* unpartnered, for a principled reason.

Adding contextually supplied spatial axes to the semantics would be a lot to swallow if they existed merely to handle extent readings. However, spatial axes seem to be quite well motivated by other phenomena. Consider (22a) and (22b). Following Fong (1997), I will call these *diphasic locatives*.

(22) a. the road (in)to Ukiah
b. the road out of Ukiah
c. The road into Ukiah widens 5 feet at the wall.
d. The road out of Ukiah narrows 5 feet at the mall.

Sentence (22a) describes a particular road as a path into Ukiah; in (b), the same road may be a path out of Ukiah. Two perspectives are taken on the same road, differing in some way that imposes directionality on how the road is viewed. Fong accounts for such directionality by use of an oriented spatial axis. Space precludes a detailed consideration of her account; two points are important. The first point is that an axis is required. Call this the *axis of reference*. The second point is that the directionality of Fong's axis interacts directly with extent readings. Sentence (22c) asserts that the road's width at the mall increases in the direction toward Ukiah, that is, in the same direction as Fong's axis points; (22d) asserts that it decreases in the direction away from Ukiah, again the direction of the spatial axis. We can account for this if we simply assume that the axes of reference in (22a) and (22b) are identified with the axes of change.

A more familiar example arises in the case of projective prepositions such as *behind, in front of, in back of, above, below, beside,* and *ahead of*:

(23) a. The futon is behind/beside the chair.
b. The futon is behind the boulder.

In (23a) the futon's location can be described as *behind* the chair, which we will call *the ground*, because a chair is the kind of object that has a canonical back and front, determining the direction of an axis from the front through the back. I will call this kind of axis of reference, in which the ground has a canonical orientation that determines the direction of the axis, *intrinsic*, following Fillmore (1971), Tversky (1996). In (23b), the boulder has no such canonical sides and some contextually determined point (let us call it a point of view) must determine the direction in which "behind" lies. What unifies these examples with those in (22) is that directionality is involved, and this directionality seems to be describable via an axis that goes through the ground, Ukiah in (22), the chair and boulder in (23). (23c), reproduced from the introduction, shows that the directionality of projective PPs, like that of diphasic locatives, interacts with extent readings. The direction in which the dress's length must increase in (16) is from the dress's front toward its back, that is, the same direction as its intrinsic front-to-back axis. In brief, the axis of reference is identified with the axis of change.

To flesh these ideas out, let us begin with the analysis of the degree achievements. What is going on in the event reading of (1b)? Widths may vary in time; and events of widening in time are events in which the width of the theme at the beginning of the event differs from the width at the end. What is going on in the extent reading of (1b)?

The key idea of GHKL analysis is that (1b) exploits a contextually provided spatial axis to measure out change. Thus we find if we measure the width of the crack moving up along that axis in the selected interval that it is increasing. What does it mean to measure width "up along" a spatial axis? It means the points on the axis are ordered and as we moved in the "upward" direction on the axis, the width increases. What does it mean to measure the width of an object x "at a point" s on an axis? It means we imagine a plane P perpendicular to the axis and measure the width of the intersection of P with x. This means that we can have a single function

$$\mathrm{wide}(\sigma)(i)$$

that returns widths for the figure of state σ for an index i whether i is spatial or temporal. For clarity we will refer this function as $\mathrm{wide_T}$ when the arguments are temporal and $\mathrm{wide_S}$ when the arguments are spatial. I will reserve wide$_{\mathrm{I}}$ (I for "index") to schematize over both cases).

Again, the introduction of a contextually provided spatial axis is independently motivated, this time very specifically by the semantics of width:

(24) a. The cabinet is 6 feet wide.
b. The boulder is 6 feet wide

Here the cabinet has canonical orientation axes, with one usually favored for widths, but the boulder does not. It must be context, "point of view", that orients the axis. The axis along which widths are measured, called the measurement axis, must be perpendicular to the front-to-back axis in (1b), along which widths may change. The front-to-back axis is the axis of reference. The essential claim of the analysis is that in the extent readings of sentences like (1b) the axis of reference may be exploited as an axis of change.[8]

[8]Extent readings for degree achievements, however, are not restricted to clearly spatial adjec-

The fact that the axis of reference used an axis of change must be perpendicular to the axis of measurement is a consequence of the fact that we are dealing with the semantics of change. Each absolute axis of measurement should yield exactly one value for the relevant measurement, one width in the case of *wide*, one length in the case of *lengthen*. Varying measuring planes along the axis of change gives us varying measurements. The infelicity of (15b) may be viewed as an attempt to exploit an axis of change that coincides with the axis of measurement. The felicitous (16) fixes this problem.[9]

Motivated by examples like (24), I assume that every token of *wide* exploits an axis of reference S, whether it functions as an axis of change of not. Sentence (24b) may be then used to make two sorts of claims: (a) the boulder has a certain width consistent with the axis of reference S at a certain time t; or (b) the boulder has a certain width at a certain point s on S. Reading (a) is a temporally indexed reading; reading (b) is spatially indexed. Reading (a) presupposes the width of the boulder is constant along the axis of reference, at least up the current standards of precision in force. Reading (b) does not.

Reading (b) may be forced by the addition of a locative phrase:

(25) The boulder is 6 feet wide where the fence crosses it.

Formally, we need to distinguish the following two possibilities:

(26)

(a)	$\mathrm{wide}^{\mathrm{S}}_{\mathrm{T}}$	state function with temporal domain and ref. ax. S
(b)	$\mathrm{wide}^{\mathrm{S}}_{\mathrm{S}}$	state function with spatial domain and ref. ax. S

These alternatives are not quite symmetric. With a temporal state function, any spatial axis through the figure is in principle a possible axis of reference; with a spatial state function using S as the axis of change, only S may be the axis of reference.[10] We thus write:

$$\mathrm{wide}_{\mathrm{S}}$$

tives. Any degreeable adjective whose degree can change with respect to space while time is held constant can yield an extent reading:

(i) The sky pinkened in the east.

We assume then, that a reference axis may be supplied for any such adjective.

[9]This will be formalized in section 3.3 in the form of the **incrementality principle**, a condition on the domain of the INCREASE operator.

[10]See Gawron (2005) for discussion.

for $\mathrm{wide}^{\mathrm{S}}_{\mathrm{S}}$.

Given this picture, the analysis of degree achievements from HKL can just be carried over straightforwardly. We assume the semantics of a simple adjectival use of *wide* is:

(27) a. The crack is a half inch wide.
b. $\exists \sigma[\mathrm{wide}^{\mathrm{S}}_{\mathrm{T}}(\sigma)(t) = [.5\,\mathrm{in}] \wedge \textit{figure}(\sigma) = c\,]$

Here t is some contextually provided moment of time. The subscript T tells us this is a use of *wide* as a function of times (not locations), and the superscript S denotes the spatial reference axis.

In the rest of this section we sketch the basic analysis for the following simple case:

(28) The crack widened half an inch.

To begin with, here is a slightly modified version of the axiom HKL use to define increase:[11]

(29)
$$\forall t_1, t_2, x, d \left[\begin{array}{l} \exists e\,[\,\mathrm{increase}(\mathrm{wide}^{\mathrm{S}}_{\mathrm{T}})(e) = d \wedge \\ \qquad \mathrm{START}(e) = t_1 \wedge \mathrm{END}(e) = t_2 \wedge \textit{theme}(e) = x\,] \\ \qquad\qquad\qquad \longleftrightarrow \\ \quad \exists \sigma_1, \sigma_2[\,\mathrm{START}(\sigma_1) = t_1 \wedge \mathrm{END}(\sigma_2) = t_2 \wedge \\ \qquad\qquad \textit{theme}(\sigma_1) = \textit{theme}(\sigma_2) = x \wedge \\ \qquad\qquad \mathbf{wide}^{\mathrm{S}}_{\mathrm{T}}(\sigma_1)(t_2) = \mathbf{wide}^{\mathrm{S}}_{\mathrm{T}}(\sigma_2)(t_1) + d\,] \end{array}\right.$$

A widening event is one that relates to two width states, the width state of the theme at the event's beginning and the width state of the theme at the end, with the difference in width measures, d, equaling the width increase of e:

$$\mathrm{increase}(\mathbf{wide}^{\mathrm{S}}_{\mathrm{T}})(e) = d$$

The revision required to admit extent readings is simply to make *increase*, START, and END all sensitive to what axis change is being measured on. Using I

[11]The modification is that adjective meanings have a state argument, and a Neo-Davidsonian style of breaking out roles has been used.

for the axis of change, whether temporal or spatial, and i_1, i_2 for indices on the axis, we would substitute the following into (29):

$$\ldots \textit{increase}_{\mathrm{I}}(\textbf{wide}^{\mathrm{S}}_{\mathrm{I}})(e) = d \ldots$$
$$\ldots \mathrm{START}_{\mathrm{I}}(e) = i_1 \wedge \mathrm{END}_{\mathrm{I}}(e) = i_2 \;\ldots$$
$$\longleftrightarrow$$
$$\ldots \mathrm{START}_{\mathrm{I}}(\sigma_1) = i_1 \;\wedge \mathrm{END}_{\mathrm{I}}(\sigma_2) = i_2 \;\ldots$$

I, the axis the INCREASE operator exploits, is the axis of change. When I is spatial it must be a contextually supplied axis, and the most salient one is the adjectival axis of reference S, each index of which determines a cross-section of the theme with a (potentially different) width. When I is temporal, we simply have the case of (29) again.

The definition of the START of an event with respect to an axis is:[12]

(30) $\mathrm{START}_{\mathrm{I}}(e) \;=\; \underset{p \in \mathcal{T}(e)}{\mathrm{Min}}\ \mathrm{coordinate}(I,\, p)$

where $\mathrm{coordinate}(I,\, p)$ is the coordinate of point p along axis I. Thus, the start and end of e along axis I are the respective minima and maxima of the projection of e's spatiotemporal trace, $\mathcal{T}(e)$, onto I. An event will thus have different starts and ends, depending on what axis is used.

We have now said enough to address the case of (28):

(31) a. $\exists\, e\ \left[\textit{increase}_{\mathrm{S}}(\mathrm{wide}_{\mathrm{S}})(e) = [.5\,\mathrm{in}] \wedge \textit{theme}(e) = c\ \right]$

b. $\exists\, e\ \left[\textit{increase}_{\mathrm{T}}(\mathrm{wide}_{\mathrm{T}})(e) = [.5\,\mathrm{in}] \;\wedge \textit{theme}(e) = c\ \right]$

The extent reading of (28) is represented in (31a) as the choice of S, the axis of reference, as the axis of change subscripting *increase*; the event reading in (31b) as the choice of T, time, as the axis of change. According to our revised version of (29), both readings are true if and only if the difference in the value of the width function between the start and end of e as measured on the axis of change S is .5 inch.

As noted in the introduction, this analysis of the ambiguity of (28) makes no use of an aspect-changing operator, such as the inchoative operator used in the analysis of extent predicates in Jackendoff (1990), to distinguish the readings. Essentially the same meaning is claimed to yield both readings, the difference residing in which axis is used for the evaluation of change. This makes the prediction

[12] $\mathcal{T}(e)$ is Krifka's (1998) spatiotemporal trace function.

that the extent readings and event readings for *widen* have essentially identical aspectual properties.

The sentences in (32) illustrate this. The verb *widen* falls into a sizable class of degree-achievement verbs that can be both activities and accomplishments, as shown in (a) and (b). The corresponding ambiguity between spatial activity and spatial accomplishment is shown in (c) and (d), which repeat (2):

(32) a. The crack widened five inches in five minutes.
b. The crack widened for several hours.
c. The crack widened nearly half an inch in ten meters.
d. The crack widened for 100 yards.

Thus, the extent readings for *widen* preserve exactly the aspectual properties of the event readings. This is entirely in line with the HKL theory: Telicity should be determined only by the semantic properties of the degree, and the semantics of the degree in extent and event readings are unchanged on this analysis. As we shall see below, however, not all extent/event ambiguities are aspect-preserving in this sense.

3 Paths and extent readings

We now turn to the task of an analysis of paths that can be integrated with the idea of spatial axes.

We begin by defining an operator path which, for each appropriate event, will return the state function that tracks the location of the event's *theme* with respect to either space or time. The path operator will serve two functions:

(a) account for the use of path phrases with motion predicates, what is usually thought of as the basic sense of path phrase like *from Boston* and *to the ridge*;
(b) account for the use of path phrases in extent readings like those of (1).

3.1 Path operator and events

In this paper I will assume an operational distinction between **roles** and **operators**. For our purposes, both are functions on events. But roles return individuals and operators return functions. Thus the **theme role** is a function on events that for each event returns an entity moving or being located in that event. The *path operator* on the other hand returns a function. Despite the risk of confusion I will often refer to the function returned by the path operator as the path (just as I refer to the entity returned by the theme function as the theme).[13]

I will thus write

$$\textbf{path}(e)$$

to denote the path function associated with event e, if e is an event of the appropriate type. Thus **path** is the path-operator and $\mathrm{path}(e)$ the path-function it returns for e.

The key property of path functions for our purposes is that they are always defined relative to an axis.

$$\textbf{path}_{\mathrm{T}}(e)(t)$$

is the location of the theme at time t. This then is a **temporally indexed path**.

$$\textbf{path}_{\mathrm{S}}(e)(s)$$

is the location of the slice of the theme that intersects the plane through axis S at s. This is a **spatially indexed path**.

Note that both temporally and spatially indexed paths return regions when applied to indices, but for 3D objects, temporally indexed paths typically return 3D regions, and spatially indexed paths **always** return slices, planar cross sections of the theme. As we shall see this will be sufficient to predict certain structural differences between temporal and spatial paths.

For any path function π, whether temporal or spatial, The domain is that set of points on the axis I that fall within e:[14]

$$\textbf{path}_{\mathrm{I}}(e) = \pi \quad \text{only if} \quad \pi : [\textsc{start}_{\mathrm{I}}(e),\ \textsc{end}_{\mathrm{I}}(e)] \rightarrow \mathrm{Locations}$$

Thus, there are many path functions for any given event, corresponding to the starts and ends determined by each axis through it.

Two consequences of this definition are worthy of special note. First, when paths are defined with respect to spatial indices, there is no motion entailed. What changes from index to index with a spatially indexed path is the parts of the theme being located. As I will illustrate in the next section, this *generalized notion of path* will yield both extent and event readings for motion predicates. The unifying idea is not motion but an axis along which location is tracked.

[13]The idea of representing paths through the use of functions from events to times to locations is anticipated in Verkuyl 1978, Verkuyl 1993. This model of path is also consistent with axioms of Krifka (1998).

[14]See the appendix for the full definitions of temporal and spatial path functions.

The second point is that paths are event-relative; they are defined to respect the boundaries of their events. This feature invites the definition of a path-determined (and therefore axis-determined) ordering on events:

(33) $e_1 \sqsubseteq_S e_2$ iff $\textbf{path}_{\mathrm{S}}(e_1) \subseteq \textbf{path}_{\mathrm{S}}(e_2) \wedge e_1 \sqsubseteq e_2$

Read $e_1 \sqsubseteq_S e_2$ as e_1 is a subpart of e_2 along axis S. Here $\subseteq$, which means "subpath of", is just the natural ordering on functions:

$$f_1 \subseteq f_2 \text{ iff } \mathrm{Dom}(f_1) \subseteq \mathrm{Dom}(f_2) \quad \text{and} \\ \forall x, y\, [\, \langle x,\, y\rangle \in f_1 \rightarrow \langle x,\, y\rangle \in f_2]$$

An event e_1 is a subpart of an event e_2 along axis S if and only it is a subpart of e_2 and the path of e_1 along axis S is a subpath of the path of event e_2. This will entail that both events have a theme, that the themes of the two events are the same, and that the theme's location in the two events agrees wherever it is defined for both events.

In section 3.4, we will use this ordering to define a notion called axial cumulativity which will serve the dual purposes of defining the appropriateness conditions for spatial frame adverbials and characterizing extent predicates.

3.2 Extent verbs

The path operator can be directly applied to Jackendoff's extent verbs and the larger class of path-shape verbs, all of which involve motion on their event readings. For example, consider *extend* and *zigzag*:

(34) **Path property verbs**

a. *extend*: $\textit{extend}_{\mathrm{S}}(e) = \pi$ iff $[\textit{path}_{\mathrm{S}}(e) = \pi]$

$\textit{extend}_{\mathrm{T}}(e) = l$ iff $[\mathrm{INCREASE}_{\mathrm{T}}(\textit{path}_{\mathrm{T}})(e) = l]$

b. *zigzag*: $\textit{zigzag}_{\mathrm{I}}(e) = d$ iff $\mathrm{ZIGZAGGY}(\textit{path}_{\mathrm{I}})(e) = d$

The treatments of *extend* and *zigzag* contrast in several respects. For one thing, an aspectual contrast has been posited between event and extent readings for *extend*, but not for *zigzag*. We take these cases in turn.

The first equation in (34a) really does two jobs. It defines the predicate *extend* in terms of the path operator; and it defines how path expressions constrain the state σ. We assume a PP like *from Boston* denotes a property of paths:

$$[\![\textit{from Boston}_{\mathrm{S}}]\!] = \lambda\pi[\pi(\textsc{start}_{\mathrm{S}}(e)) \text{ overlaps Boston}]$$
$$= \text{a property true of a path if the path evaluated at minimal member of its domain overlaps Boston}$$

The first equation in (34a) captures extent readings with *extend*. It introduces a spatial path, $\textit{path}_{\mathrm{S}}$, into the described state σ, which requires that the theme of σ be extended along the path of σ. The bracketed $[v : r]$ in (35) is an abbreviation designating a property of path functions true if they begin at valley v and end at ridge r. Specifically, at the minimal index of the event, the theme must overlap the valley and at the maximal index the ridge.

(35) a. The fog_f extended from the valley floor_v to the ridge_r
b. $\exists\sigma[\textit{extend}_{\mathrm{S}}(\sigma) = \pi \wedge \textit{theme}(\sigma) = f \wedge [v : r](\pi)]$

So much for the extent reading.

We turn to the event reading:

(36) $\exists\sigma[\textsc{increase}_{\mathrm{T}}(\textit{extend}_{\mathrm{T}})(\sigma) = l \wedge \textit{theme}(\sigma) = f \wedge [v : r](\textit{path}_{\mathrm{T}}(e))]$

Here, the use of the INCREASE operator may be somewhat surprising. Path is a function that returns locations. What does it mean for locations to be *increasing* and what does it mean for the location of the *theme* in an event e to increase by an amount l?

We assume that

$$l_1 \sqsubseteq l_2$$

if and only if l_1 is a subregion of l_2. Thus we assume a **partial** ordering on regions; two regions are ordered if and only if one is a part of another. Using the terminology of mereological accounts [15], we call this a **part-of** relation. Schematically, INCREASE is defined as follows:

$$\begin{aligned} \text{increase}(\alpha)(e) = d \ \text{ iff } \exists\sigma_1\,\sigma_2\ & \alpha(\sigma_1) = d_1 \wedge \textsc{start}(\sigma_1) = \textsc{start}(e) \wedge \\ & \alpha(\sigma_2) = d_2 \wedge \textsc{end}(\sigma_2) = \textsc{end}(e) \wedge \\ & d_1 + d = d_2 \end{aligned}$$

[15] Mereological accounts of lexical aspect are pursued by a number of authors (Filip 1999, Krifka 1998, Krifka 1989, Pinon 1994a, Pinon 1994b) and are based on homomorphisms between participants of events and events preserving part-whole relations. Relevant participants include (incremental) themes and paths.

So to extend this to regions, we need to define a unique d that will function as the difference argument d.

This can be done via the **relative complement** of two regions l_1 and l_2, written l_1/l_2

$$l_1/l_2 = \underset{l}{\text{argmax}}[\, l \sqsubseteq l_1 \wedge \neg l \otimes l_2\,]$$

where $\otimes$ is the overlap relation,[16] which holds between two regions l_i and l_j when there is some region that is part of both. Then:

$$d_1 + d = d_2 \text{ iff } d = d_1/d_2$$

The value of the difference argument with region-returning state-functions, then, will be the region the theme spreads through. The use of the INCREASE operator in (34a) captures a basic descriptive fact: The motion in event readings of *extend* is **spreading motion** (see Sections 1 and 3.2) as opposed to displacement. The location of the theme at the end of the extending event **includes** the location at the beginning.

On an event reading of *A extended from B to C*, spreading motion is involved, because A remains in contact with B throughout the event. Thus, the INCREASE operator extends naturally from degrees to a mereological domain and exactly captures the spreading motion of *extend*. We will see when we turn to *cover* that a similar effect obtains there. Notice however that the INCREASE operator cannot capture incremental motion. The location of an entity at the end of an ordinary incremental movement does not include its location at the beginning. Thus we cannot capture the semantics of *The halfback zigzagged to the goal line* via INCREASE.[17]

We turn then to the correct semantics for of *zigzag*. The definition in (34b) says that an event is a zigzag event along axis I if and only if there is a π such that π is the path of e and π is zigzaggy to some degree d. I will assume for now that

[16] See the appendix for the definition.

[17] This analysis is a little out of keeping with the program of Kennedy and Levin (2001), which proposes to account for all gradual change with state functions that map to degree domains. In contrast I have opted for a state-function that maps to a mereological domain. The central motivation here is to get the truth conditions right. Note in particular that we don't get the right truth conditions if we measure change in a totally ordered degree domain like volume. Measuring change with volume is correct for a verb like *inflate*, where the truth conditions really do require an increase in a scalar measure, but *extend* incorporates the additional requirement that the spatial region occupied at the end of the event include the region occupied at the beginning, and this is exactly captured by the sub-region relation.

the value of the zigzag function is an integer, roughly the number of zigs and zags the path makes. I will argue for this account in Section 5[18] Thedegree predicate ZIGZAGGYNESS measures a degreeable property of the outline of the path, one which cross-cuts extent and event readings. Again, as with *widen* event and extent readings differ only in whether axis is the axis of change is temporal or spatial. Sentence (37) provides an example:

(37) a. Mist$_m$ zigzagged from the valley floor$_v$ to the ridge$_r$
b. $\exists e,\ d[\textit{zigzag}_{\mathrm{S}}(e) = d \wedge \textit{theme}(e) {=} m \wedge [v : r] \circ \textbf{path}_{\mathrm{S}}(e)]$

The definition of *zigzag* differs from the definition of *extend* in introducing a degreeable function *zizaggy*. The primary motivation for this was discussed in the introduction. The verb *zigzag* is modifiable by adverbs of degree:

(38) a. The road zizagged/?extended sharply/gently up the hill.
b. The 4x4 zigzagged sharply/gently up the hill.

To this we may add the existence of verbal comparatives:

(39) I 5 zigzags a good deal less than I 80.

As we shall see this difference will be crucial in capturing the differences in graduality between *zigzag* and *extend*. Note that degree sensitive adverbs co-occur with other path-shape verbs as well:

(40) a. The road curved/rose sharply up the hill.
b. The road climbed steeply.

Indeed, some members of the class *rise*, *ascend*, and *climb* are often analyzed as degree achievements related to some adjective like *high*. What I am basically suggesting is that a large are all degreeable predicates. I will discuss some exceptions in Section 5.

[18]That is, the idea is simplay to count the number of sharp direction changes in the path, as suggested by such examples as *The road zigzagged 5 times en route to the summit*. This might also be a reasonable analysis of semelfactive verbs such as *jump* and *flash*: they are verbs of gradual change whose state functions return integers counting the number of times some basic "step" is iterated.

3.3 Paths for degree predicates

We now address the question of how the definition of path interacts with the analysis of *widen* sketched in the previous section.

First, note that path phrases occur with the adjective *wide* as well as with the degree achievement verb:

(41) The canyon was six feet wide from the North $\mathrm{End}_{\mathrm{n}}$ to the trail $\mathrm{head}_{\mathrm{t}}$.

Since we have assumed that *wide* denotes a function evaluable either *at a moment in time* or *at a point in space* the question arises: Which kind of function is being used here? The only answer consistent with the truth conditions of (41) seems to be that the temporal function is being used: The width measurement in (41) is true at some contextually available past instant of time over an entire spatial interval.[19] The spatial interval is being determined by an axis of reference running from the north end to the trail head, as described by a spatial path phrase in our sense. Thus we have width as a function of time co-occurring with a spatial path phrase.

We make the following assumptions about the adjective *wide*:

(a) It is lexically specified to take spatial paths (temporal paths are out, because there is no motion).
(b) The width function may be either temporally or spatially indexed.
(c) Let **width** be a primitive width measurement function giving widths of spatial regions. Then we assume:

$$\text{(a)}\quad \mathrm{wide}_{\mathrm{S}}(\sigma)(s) = \mathrm{width}(\mathit{path}_{\mathrm{S}}(\sigma)(s))$$
$$\text{(b)}\quad \mathrm{wide}^{\mathrm{S}}_{\mathrm{T}}(\sigma)(t) = \mathrm{width}(\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}(\sigma)(t))$$

This path operator in (b) is neither the $\mathbf{path}_{\mathrm{S}}$ in (a) nor the $\mathbf{path}_{\mathrm{T}}$ introduced above. It is a way of defining a temporally indexed path function for a predicate which is basically a spatial path predicate. The definition is:

(42) $$\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}(e)(t) \quad = \quad \mathrm{AT}(\mathrm{theme}(e), t) \bigsqcap \mathrm{Loc}(\mathit{path}_{\mathrm{S}}(e))$$

[19] We are not assuming a temporal spatial asymmetry here; we are focusing on the case that is relevant for developing the examples of Section 1. Note that width claims can be made over temporal intervals as well:

(i) The flood channel was 3 feet wide from 3 to 4 o'clock.

This in fact does seem to have a reading completely parallel to (41), that there is a contextually available point in space at which the channel was 3 feet wide over the given temporal interval.

Loc is a function returning the entire spatial region covered by a path function, defined as:

$$\mathrm{Loc}(\pi) = \bigsqcup_{s \in \mathrm{Dom}(\pi)} \pi(s)$$

For any time t, $\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}(e)(t)$ is the location of the theme of e restricted to the interval determined by the spatial path of e. This, then, is a time sensitive path function that does not entail motion. If the theme of e is a wall and the path is restricted to be from the north gate to the tower, $\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}(e)(t)$ returns the portion of the wall between the north gate and tower at time t.

This means we now have two distinct kinds of temporally indexed path, $\mathbf{path}_{\mathrm{T}}$ (section 3.1) and $\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}$. We will call $\mathbf{path}_{\mathrm{T}}$ an **incremental path** and $\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}$ a **non-incremental path**. These varieties of path are distinguished by two semantic properties:

(43) (a) Incremental paths are incremental themes in the sense of (Dowty 1991); that is, the truth conditions require that the path covered grow homomorphically with the event, with the location identified in the *from* phrase overlapped at the beginning of the event, and the location identified in the *to*-phrase overlapped at the end
(b) incremental paths entail motion.

These properties are illustrated in (44):

(44) Incrementality

[+ Incr$_e$]	(a)	A storm front zigzagged from Prescott to the border.
	(b)	The fog extended from the pier to the point.
[- Incr$_e$]	(c)	The crack widened from the tower to the north gate.
	(d)	Fog covered the peninsula from the pier to the point

First, for the cases marked [- Incr$_e$], the paths are not incremental themes. In particular, on the non-incremental event reading of (c) the progression of the crack's widening may be in any order, say, from gate to tower, as long as the event concludes with a widening that covers that span; and in (d) the fog's progress may be in any order as long as in the end a span between pier and point is covered.

Second, for the non-incremental case there is no movement entailed. There is no sense in which the crack has to change location. It may appear everywhere along the indicated path simultaneously, as long as it is widening. Similarly, on the event reading of (d), the fog, as it often does, may simply condense in place, thickening over the course of the event.

In contrast, the [+ Incr] versions of (44) have paths which are incremental themes, and do entail motion.

In sum, with non-incremental paths the axis of change is not the same as the path axis (this is exactly what the definition in (42) achieves); in incremental paths it is. The intuition seems to be that the [+ Incr] verbs are somehow legitimately (or basically) verbs of movement; the [- Incr] verbs are not.

We thus assume that the semantics of (41) is:

(45) $\exists\sigma[\mathrm{wide}^{\mathrm{S}}_{\mathrm{T}}(\sigma)(t) = [6\,\mathrm{ft}] \wedge \textit{theme}(\sigma){=}c \wedge [n:h] \circ \mathbf{path}_{\mathrm{S}}(\sigma)]$

Here t is a contextually provided time index. The path operator in (45) will require that the path of state σ run along some spatial axis that places σ's start in some location overlapping the North end and σ's end in some location overlapping the trail head at time t.

This completes the account of the semantics of the adjective *wide* with paths. We extend the account to *widen* simply by assuming that the $\mathrm{INCREASE}_{\mathrm{T}}$ operator preserves the spatial path of the start and end states. This is guaranteed by the following modified version of axiom (29):

(46) $$\forall e, d \left[\begin{array}{l} \textit{increase}_{\mathrm{I}}(\mathbf{wide}^{\mathrm{S}}_{\mathrm{I}})(e) = d \\ \qquad\longleftrightarrow \\ \exists\sigma_1, \sigma_2[\ \mathrm{START}_{\mathrm{I}}(\sigma_1) = \mathrm{START}_{\mathrm{I}}(e) \wedge \mathrm{END}_{\mathrm{I}}(\sigma_2) = \mathrm{END}_{\mathrm{I}}(e) \wedge \\ \qquad \mathbf{wide}^{\mathrm{S}}_{\mathrm{I}}(\sigma_1)(\mathrm{END}_{\mathrm{I}}(e)) = \mathbf{wide}^{\mathrm{S}}_{\mathrm{I}}(\sigma_2)(\mathrm{START}_{\mathrm{I}}(e)) + d \wedge \\ \qquad \mathbf{path}_{\mathrm{S}}(\sigma_1) \subseteq \mathbf{path}_{\mathrm{S}}(e) \wedge \mathbf{path}_{\mathrm{S}}(\sigma_2) \subseteq \mathbf{path}_{\mathrm{S}}(e)] \end{array}\right.$$

This axiom basically states that to extend width states out along any axis their axes of reference S must be the same as that used by e and their spatial paths must be extended. The change to axiom (29) is that the requirement that the themes of σ_1, σ_2 and e be the same has been strengthened to the requirement that the spatial paths of σ_1, σ_2 be subsets of the spatial path of e.

Thus the definitions of *wide* and *increase* lead to an immediate account of the semantics of path expressions with *widen*, illustrated in (47b), which gives the extent reading for (47a):

(47) a. The crack widened 5 inches from the North gate to the tower.

b. $[\![\exists e\ [\textit{increase}_{\mathrm{S}}(\mathrm{wide}_{\mathrm{S}})(e) = [.5\,\mathrm{in}] \wedge \textit{theme}(e){=}c \wedge$
$[\mathrm{ng}:\mathrm{t}] \circ \mathbf{path}_{\mathrm{S}}(e)]]\!]$

c. $[\![\exists\, e\ \ [\textbf{increase}_{\mathrm{T}}(\textbf{wide}^{\mathrm{S}}_{\mathrm{T}})(e) = [.5\,\mathrm{in}]\ \wedge\ \textit{theme}(e) = c\ \wedge$
$[\mathrm{ng : t}] \circ \textbf{path}^{\mathrm{S}}_{\mathrm{T}}(e)]]\!]$

The path expressions constrain the path which in turn determines the domain over which the change measurements are taken. The minimal point of e along axis S must overlap the north gate and the maximal point must overlap the tower. The difference in width between those two extremes must be a half-inch.

Summing up, in this section I have proposed an analysis of spatial and temporal paths that accounts for both verbs of motion and extent verbs. The analysis extends naturally to account for the use of path phrases with stative predicates like the adjective *wide* and degree achievements like the verb *widen*.

Note that the domain and range of the path function of *widen* has not changed in this section. It is still a mapping from indices to widths. What has changed is that the measurements are now being constrained by the path-function. Thus we have simply recast *wide* as a function that measures widths along a path.

3.4 The incrementality principle

In this section we propose the **incrementality principle**, which provides some semantic motivation for the connections of axes, paths, and extent readings.

[rewrite next par]

Gawron (2005) argues that extent readings with degree achievements are restricted to predicates with spatial paths. Summarizing, INCREASE must apply to a predicate which is stative relative to the axis of change. On an extent reading that axis is some spatial axis S, and this turns into the requirement that the predicate be cumulative relative to the path axis. A version of cumulativity called path-cumulativity is proposed, revising the definition of cumulativity in Zwarts (2005).

Formally, we will require of such states that they be *axially cumulative*.

(48) *Axial Cumulativity* [20] A property P is **cumulative with respect to axis S** iff

$$\forall e_1,\, e_2\quad [\mathrm{P}(e_1) \wedge \mathrm{P}(e_2) \wedge \exists\, \pi\, \textbf{path}_{\mathrm{S}}(e_1 \oplus e_2) = \pi\,] \rightarrow \mathrm{P}(e_1 \oplus e_2)`$$

[20] The idea of emphasizing cumulativity in the context of paths is due to Zwarts (2005), who argues that cumulativity is the relevant concept for identifying telicity where paths are concerned, and argues against Krifka's notion of quantization (Krifka 1992,1998). The arguments appear to carry over to this construction of paths, and the definition of cumulativity given is a translation of Zwarts's notion to this framework. Below I apply it to the problem Zwarts intended it for, telicity.

The definition of axial cumulativity says that a property P is cumulative with respect to axis S iff when you sum two P-events and a path exists on axis S for that sum, then P holds of of the sum. Of course this definition only makes sense for events which are defined for a path function;

This definition can be immediately applied to the problem of (49), repeating (15b):

(49) The cable lengthened in the den.

I claim cable width is axially cumulative along the cable length axis. Suppose we have two width events, σ_1 and σ_2, for cable c with length axis S, both bearing the property

$$\text{P} = \lambda e[\textbf{\textit{theme}}(e)\!=\!c \wedge \textbf{\textit{wide}}_S(e)(t) = [\text{2 inch}]\,]$$

If the sum of σ_1 and σ_2 along S has a well-defined path, then we have a larger event $\sigma_1 \oplus \sigma_2$ of which P is still true, that is, a larger event of a cable being two inches wide.

In contrast, properties like *wide* and *long* will never be axially cumulative along the measurement axis. An event in which a cable is 2 feet long summed along the length axis with an event in which the same cable is 2 feet long may give an event in which the cable is 4 feet long. The reader may verify that skirt length (generally measured on a vertical axis) is axially cumulative along a front-to-back axis, making an example like (16) felicitous.

Nothing in the definition of axial cumulativity limits it to scalar properties. In fact, apart from the predicates resulting from an application of increase, it seems to be a general property of all extent predicates. What it generally identifies is properties that it makes sense to say hold of a theme at points along an axis.

To turn this into a condition on INCREASE we need a more precise definition of the kinds of functions INCREASE applies to. We will call these state functions. The predicate *wide* is a state function. A temporally indexed state function is something which, applied to state of affairs σ and a time t, returns a member of an ordered domain, in the case of wide(σ)(t), a width. For example,

$$\text{wide}(\sigma)(t) = [\text{foot } 5]$$

We will what the state-function returns a **state-value**. Mostly a state-value is a degree, but we allow for elements of any ordered domain.

We want to restrict INCREASE to apply to predicates whose state functions define axially cumulative properties:

(50) *Incrementality Principle*

$\text{INCREASE}_{\text{I}}(f)$ is defined iff for all states-of-affairs σ, indices i, and state-values x, $\lambda e[f(e)(i) = x]$ is axially cumulative along axis I.

Under this condition *long*, *wide* and *extend* are axially cumulative along the temporal axis given the definitions in section 3.2. The predicates *wide* and *long* are also axially cumulative along spatial axes which cannot be axes of measurement. Thus, a length property for cables is NOT axially cumulative for an axis along which the length of the cable can be measured, and similarly for width properties.

A more illuminating consequence of the incrementality principle is that it provides a link between the path role and extent readings. If we assume that the path operator is the unique semantic component that relativizes properties to a spatial axis, then this condition immediately explains why extent predicates should take path arguments: a path operator provides the key linguistic resource for constraining the axis.

4 Aspectual variation

We return to the varying behavior of *gradually* in the following examples, reproduced from Section 1.

(51) a. The crack gradually widened from the North gate to the tower.
b. Fog gradually covered the peninsula from the pier to the point .

The issue is that (51a) has both an event and an extent reading; but (51b) has only an event reading. The question, then, is: Why aren't extent readings for *cover* compatible with *gradually*?

The data in (51) immediately preclude two kinds of account. First, we cannot say that that *gradually* does not combine with *cover* because *cover* has an end of scale degree predicate in it. The fact is that *gradually* does combine with *cover* on the event reading, and if extent *cover* is an end-of-scale predicate, then surely event *cover* is as well. The verb *cover* is just like other incremental theme predicates: In each sub event the part of the theme that is covered is completely covered, just as the part of an apple that is eaten is eaten; matters progress because parts that are completely covered can belong to larger things that are not, and *gradually* is quite compatible with this kind of progress. The question is: Why does that kind of progress count as progress along the temporal axis but not on the spatial axis?

The second kind of account precluded by (51) is any account that says that *gradually* is incompatible with change along a spatial axis; *gradually* works quite well with the extent reading of *widen* in (51a).

What then distinguishes the extent reading *cover* from the extent reading of *widen*? First, recall that, as shown in (3), extent *cover* shows no evidence of being an accomplishment: As suggested in the discussion in Section 1, there is evidence that that *cover* on the extent reading, expresses a state. The problem is that *gradually* requires a verb of gradual change, and while extent-*widen* falls into that class, extent-*cover* does not. Within the parameters of the current account, the most natural way to capture this is to say that the verb *cover* does not have a semantics expressible as with the $\text{INCREASE}_{\text{S}}(\text{cover}_{\text{S}})$, and that what appears to be the extent reading is just a stative use. The assumed differences between *widen* and *cover* are shown in (52):

(52)

	Reading	Form	Semantics
(a)	Spatially indexed State	[$_{\text{V}}$ cover]	$\text{cover}_{\text{S}}(e)(s)$
(b)	Temporally indexed State	[$_{\text{V}}$ cover]	$\text{cover}^{\text{S}}_{\text{T}}(e)(t)$
(c)	Event	[$_{\text{V}}$ cover]	$\text{INCREASE}_{\text{T}}(\text{cover}^{\text{S}}_{\text{T}})(e)$
(d)	Spatial Accomplishment	*	$\text{INCREASE}_{\text{S}}(\text{cover}_{\text{S}})(e)$
(e)	Spatially indexed State	[$_{\text{A}}$ wide]	$\text{wide}_{\text{S}}(e)(s)$
(f)	Temporally indexed State	[$_{\text{A}}$ wide]	$\text{wide}^{\text{S}}_{\text{T}}(e)(t)$
(g)	Event	[$_{\text{V}}$ widen]	$\text{INCREASE}_{\text{T}}(\text{wide}^{\text{S}}_{\text{T}})(e)$
(h)	Spatial Accomplishment	[$_{\text{V}}$ widen]	$\text{INCREASE}_{\text{S}}(\text{wide}_{\text{S}})(e)$

This treatment solves a potential problem for the HKL analysis of *cover*:

(53) a. The men widened the road for several days.
b. The tailor widened the pants in 20 minutes.
c. Fog covered the pylons from the pier to the point in several hours.
d. Fog covered the pylons from the pier to the point for several hours.

On the HKL analysis, the standard explanation for activity accomplishment ambiguities is that a pragmatically supplied degree argument may either be bounded or unbounded, depending on pragmatic factors. In (a) the degree is unbounded, the road widening is not necessarily completed, and an activity property is asserted of the event. In (b), there is a pragmatically supplied endpoint to the activity (when the pants are wide enought to be worn, for instance), and an accomplishment property is asserted of the event. The contrast may also be shown by adding another clause:

(54) a. The men widened the road for several days, but they were still not finished (widening it).
b. # The tailor widened the pants in 20 minutes but was still not finished (widening them).

However, this kind of story does not work for *cover*. There is no corresponding semantic contrast in telicity between (c) and (d).

(55) a. # Fog covered the pylons from the pier to the point in several hours, but they were still not completely covered.
b. # Fog covered the pylons from the pier to the point for several hours, but they were not completely covered.

Both sentences in (55) are odd, because both (53c) and (53d) describe completely covered pylons. The reason for this, on the analysis proposed here, is that the verb in (53c) uses the INCREASE operator, that is the semantics in (52c), and the verb (53d) does not; it uses the semantics of (52b). Thus (53b) describes a state; it also describes a completely covered set of pylons because *cover* is an end-of-scale adjective. Whatever path-defined portion of the goal is covered is completely covered.

Note that we can ask exactly the same sorts of questions about *extend*:

(56) The fog extended gradually to the point.

There is no extent reading. The analysis already presented in Section 3.2 posits exactly the same sort of gap for *extend*. That is, there is no spatial accomplishment predicate:

(57)

	Reading	Form	Semantics
(a)	Spatially indexed state	$[_\mathrm{V}$ extend $]$	$\textbf{extend}_\mathrm{S}(\sigma)(s) = l$
(b)	Temporally indexed state	$[_\mathrm{V}$ extend $]$	$\textbf{extend}_\mathrm{T}(\sigma)(s) = l$
(c)	Event	$[_\mathrm{V}$ extend$]$	$\textsc{increase}_\mathrm{T}(\textbf{extend}_\mathrm{T})(e) = l$
(d)	Spatial Accomplishment	*	$\textsc{increase}_\mathrm{S}(\mathrm{extend}_\mathrm{S})(e)$

The key claim of (52) and (57) is that *cover* and *extend* only combine with INCREASE when they use a temporal axis of change. In deriving the event readings from the extent readings via an aspect changing operator, this analysis shares an essential feature with that of Jackendoff (1990), with the INCREASE operator replacing his BECOME operator. The chief objection raised against that kind of analysis in Gawron (2005) was that it did not capture the fact that the aspectual natures of the predicates with event and extent readings were basically the same. But here, the data in (3) and the co-occurrence facts with *gradually* clearly argue that event and extent readings of *cover* DO have different aspectual natures, so that objection goes away.

But though this makes the account work, we are left with essentially the same question we started with. Why? What explains the gap in (52d) and (57d)? Why should $\text{INCREASE}_{\text{T}}$ combine with COVER when $\text{INCREASE}_{\text{S}}$ will not.

To explain this, let us consider a specific account of *cover* consistent with the approach taken here. The case of *extend* will work along the same lines.

Dowty (1991) points out that cover-verbs are incremental theme verbs. In fact, cover verbs have two participants that can qualify as incremental themes. Let us call the the snow and the mountain in (1d), repeated here:

(58) Snow covered the mountain.

the *theme* and *goal*, respectively. As a cover-event progresses, more and more of the goal's surface is covered; but so also is more and more of the theme's surface moved over the goal. Progress in the event requires simultaneous consumption of two areas.

A natural stative predicate capturing this basic semantic fact, as well as the sensitivity of cover predications to paths, is the following:

(59) (a) $\textbf{cover}_{\text{S}}(\sigma) = \pi$ iff $\textbf{path}_{\text{S}}(\sigma) = \pi$ and cover-path(e, π)

(b) $\textbf{cover}^{\text{S}}_{\text{T}}(\sigma) = \pi$ iff $\textbf{path}^{\text{S}}_{\text{T}}(\sigma) = \pi$ and cover-path(e, π)

where cover-path(e, π) iff

$\forall l \in \text{Loc}(\text{ON}_{\text{S}}(\text{goal}(\sigma))(\mathcal{T}(\sigma)))\exists i \in \text{Dom}(\pi)[l \in \pi(i)]$

Here two versions of stative *cover* are defined, as were two versions of the adjective *wide* and the verb *extend*, both simply returning the path when applied to a state σ, but placing the condition the condition that the path be a *cover-path* The definition of cover path may be paraphrased: For all points l on the goal of e (and falling within the trace of e) there is an index i in the domain of e's path π such that $\pi(i)$ covers l. [21]

The stative predicate *cover* has the same type as the stative predicate *extend*; it is a relation between an event and a path. Thus in principle, both predicates are amenable to combination with INCREASE. Thus we have:

$$\text{INCREASE}_{\mathrm{T}}(\textbf{cover}^{\mathrm{S}}_{\mathrm{T}})$$
$$\text{INCREASE}_{\mathrm{T}}(\textbf{extend}^{\mathrm{S}}_{\mathrm{T}})$$

Since $\textbf{path}^{\mathrm{S}}_{\mathrm{T}}$ returns the location of theme at each moment t, restricted by the spatial path, and since INCREASE requires that area to be increasing with respect to the sub-region relation, this captures the fact that both predicates describe spreading motion of the theme on eventive readings.

The question, then, is why do not also have:

$$\text{INCREASE}_{\mathrm{S}}(\textbf{cover}_{\mathrm{S}})$$
$$\text{INCREASE}_{\mathrm{S}}(\textbf{extend}_{\mathrm{S}})$$

The crucial point for our development is the nature of the state-functions which are candidiate arguments of INCREASE. Because of the definitions of $\textit{path}_{\mathrm{S}}$ and $\textbf{path}^{\mathrm{S}}_{\mathrm{T}}$, the two state functions $\textit{cover}_{\mathrm{S}}$ and $\textbf{cover}^{\mathrm{S}}_{\mathrm{T}}$ return very different kinds of things when applied to their appropriate indices. For a given time t, $\textbf{cover}^{\mathrm{S}}_{\mathrm{T}}(e)(t)$ returns the entire portion of the theme's location that is on the goal at t; while for a given spatial index s, $\textit{cover}_{\mathrm{S}}(e)(s)$ returns the slice of the theme at s that is on the goal. While both $\text{cover}_{\mathrm{S}}$ and $\textbf{cover}^{\mathrm{S}}_{\mathrm{T}}(e)(t)$ take their ranges in the mereology of locations, $\text{cover}_{\mathrm{S}}$ does so only trivially. No two elements in the range of $\text{cover}_{\mathrm{S}}$ are ordered because the range of $\text{cover}_{\mathrm{S}}$ is a set of disjoint slices. Therefore $\text{cover}_{\mathrm{S}}$ is restricted to a range in which the elements are mutually incomparable, and it follows that this function can never be increasing. It is quite natural that it is not an appropriate argument for the INCREASE operator.

On the other hand, the range of $\textbf{cover}^{\mathrm{S}}_{\mathrm{T}}(e)$ includes spatially overlapping regions, and in particular, as was already argued for the case of *extend*, INCREASE makes sense here precisely in the case where spreading motion is described. Similar remarks apply to *extend*; INCREASE makes sense for $\textbf{extend}^{\mathrm{S}}_{\mathrm{T}}$, yielding spreading motion, but has no interpretation for $\textit{extend}_{\mathrm{S}}$.

---

[21] The spatial function ON returns the spatial region on or above its argument at a time t. ON_{S} is one of a family of path functions incorporating different spatial relations, as $\textit{path}_{\mathrm{S}}$ incorporates AT. The definition is given in the appendix.

Contrast the state functions for *wide*. Whether temporally or spatially indexed, the function *wide* takes as its range a set of degrees which are totally ordered. Thus both $\text{INCREASE}_{\text{S}}$ and $\text{INCREASE}_{\text{T}}$ may apply to it, producing spatial and temporal accomplishments.

We can formalize the account by way of what we will call the **mereology principle**.

(60) **Mereology Principle**
In order for INCREASE to combine with a state function Δ, the range of Δ must be a nontrivial mereology.

The axioms for a mereology are in the appendix, but the key requirements are:
(1) M is a join semi-lattice;
(2) M has a *relative pseudocomplement operation*; that is, it obeys the remainder principle of (85).

A join semilattice is a set of elements in which each pair of elements has a least upper bound with respect to a partial order $\leq$. Examples of mereologies include sets under the subset ordering, masses of stuff under the consists-of ordering, paths under the subpath ordering, and locations under the subregion ordering. Note also that mereologies include sets of degrees as a special case. A **nontrivial mereology** is simply one in which the partial order $\leq$ is non empty. It is this requirement which the range of cover_{S} fails to meet.

Mirroring the mereology principle we have the definition of **verbs of gradual change**:

(61) A verb of gradual change is one whose denotation is a **change function** (written Δ_e). A change function is a function from events into a nontrivial mereology.

The account of graduality, then, is simply that the adverb *gradually* has as a necessary condition that the predicates it combines with be predicates of gradual change. The two non gradual verbs *cover* and *extend* both have basic state meanings. In order to acquire change functions they must combine with INCREASE, which can combine with either $path_{\text{T}}$ or $\mathbf{path}^{\text{S}}_{\text{T}}$ to produce a Δ_e function that describes spreading motion. However, INCREASE cannot combine with $path_{\text{S}}$, so there is no spatially indexed predicate of change associated with either *cover* or *extend*. Therefore neither verb can have extent reading with the semantics of a spatial accomplishement or activity, and *gradually* is not a possible modifier.

The case of *zigzag* is even simpler, since there is no INCREASE operator in the definition; *zigzag* is simply a basic verb of change; the range of its change function is the mereology of integers.[22] Thus, *gradually*, all things being equal, is eligible to combine with *zigzag*.

Summing up the results of this section: We have accounted for the property of graduality in terms of the property of describing change. Predicates incorporating an INCREASE into their definitions necessarily describe change, and this, all things being equal, will combine with *gradually*. Predicates not definable via INCREASE may also describe change. The relevant diagnostic property there is non cumulativity.

5 Lexical classes of extent predicates

The analysis given in this paper has basically centered on four predicates *widen extend*, *zigzag*, and *cover*, which between them partition the range of variation of predicates with event/extent ambiguities. There is a small set of verbs closely related to *cover* in meaning which seems to behave like cover. These were first presented in (12) as members of the *adorning* frame of Framenet. They include *blanket, cloak, coat, and fill*. Thus, I will refer to *cover*-verbs rather than *cover*.

We have accounted for extent/event ambiguities with two distinct mechanisms. There are verbs like *zigzag* and *widen* which simply measure change of a certain kind and can use either a temporal or spatial axis to measure it on. These verbs fall in the same aspectual class for both event and extent readings. There are also verbs which require an INCREASE operator for the event readings. These are verbs like the *cover* verbs and *extend*. This is shown in (62):

(62)

Verb	Extent	Event	
widen	$\text{INCREASE}_{\text{S}}(\textit{wide}_{\text{S}})$	$\text{INCREASE}_{\text{T}}(\textbf{wide}^{\text{S}}_{\text{T}})$	Uniform Aspect
zigzag	$\text{ZIGZAGGY}(\textit{path}_{\text{S}})$	$\text{ZIGZAGGY}(\textit{path}_{\text{T}})$	
extend	$\textit{path}_{\text{S}}$	$\text{INCREASE}_{\text{T}}(\textit{path}_{\text{T}})$	Aspect Change
cover	$\textbf{cover}^{\text{S}}_{\text{T}}$	$\text{INCREASE}_{\text{T}}(\textbf{cover}^{\text{S}}_{\text{T}})$	

[22] Note that, consistent with this definition, *zigzag* must be thought of as a spatial accomplishment, not a spatial state. This can be seen, for example, from the fact that it is not cumulative. A state in which a theme zigzags 5 times combined with a state in which a path zigzags 5 times does not give a state in which the path zigzags 5 times.

We have thus assumed that, in some cases, there is aspectual variation between event and extent readings. In this section we examine the other dimensions of variation in the analysis, and identify other classes extent predicates.

We begin with some terminological necessities, defining **change function** and **state function**. The key intuition of the INCREASE operator analysis is that it takes a function of time — call it Δ_t — and returns a function of events — call it Δ_e — that measures the overall change in Δ_t in e. Call Δ_t the **state-function** of e and Δ_e the **change function** of e. For example, according to (34a), the state-function for an *extend*-event is $path_{\mathrm{T}}$, and the change function is $\text{INCREASE}_{\mathrm{T}}(\mathbf{path}_{\mathrm{T}})$. Applied to e that returns a region l which is the amount of change (amount of space extended through) in the event.

The case of *zigzag* differs from *widen*, *cover*-verbs, and *extend* in that there is no Δ_t; that is, no underlying stative predicate is assumed in its semantics. Consequently, there is no INCREASE operator in the semantics of zigzagging, merely a function which returns the degree of zigzaggyness of the path of the entire event:

Predicate	Δ_t	Δ_e
extend	$path_{\mathrm{T}}$	$\text{INCREASE}_{\mathrm{T}}(path_{\mathrm{T}})$
widen	$\mathbf{wide}^{\mathrm{S}}_{\mathrm{T}}$	$\text{INCREASE}_{\mathrm{T}}(\mathbf{wide}^{\mathrm{S}}_{\mathrm{T}})$
zigzag	NA	$\text{ZIGZAGGY}(\mathbf{path}_{\mathrm{I}})$

We shall say that a verb like *zigzag* has a change function, $\mathbf{zigzaggy}_{\mathrm{T}}(\mathbf{path}_{\mathrm{T}})$, but no state function. $\mathbf{path}_{\mathrm{T}}$ is not a state function for this verb because the difference between the start and end values for $\mathbf{path}_{\mathrm{T}}$ is NOT what the verb's change function returns for the event. Nor does does it work to bring INCREASE into the picture, using $\mathbf{path}_{\mathrm{T}}$ as the state function, because this would incorrectly predict the verb is a spreading motion verb; *zigzag* on its event readings is not restricted to spreading motion, as was shown in (10). Finally there is the possibility of feeding $\mathbf{path}_{\mathrm{T}}$ to some degree-returning function g to produce an appropriate state-function for INCREASE to apply to. But though there may be functions of a time t that would return something like the zigzaggyness of a region around t or of the entire path (as a Taylor series expansion of a function returns information about all its derivatives at a point), applying INCREASE to such a function still appears wrong. The verb *widen* describes an increase in width, but the verb *zigzag* does not describe an increase in zigzaggyness.[23] Other verbs for which parallel arguments against a

[23]Despite the absence of an INCREASE operator, note that *zigzag* can be just as much of a spatial

state-function could be made include *undulate*, *wind*, *dot*, *span*, *clutter*, *loop*, and *snake*.[24] What they all share is that the path-shape involved is a holistic property of path, not naturally expressible as a property of individual points on it. Hence we will call these **holistic path shape** verbs.

We are now in a position to formally define a degree achievement as a predicate which has both a state function and a change function. As desired, *widen* is a degree achievement with state function $\mathbf{wide}_{\mathrm{T}}$ and change function $\textsc{increase}_{\mathrm{T}}(\mathbf{wide}_{\mathrm{T}})$. The path-shape verb *zigzag* is not. All the other extent degree achievements mentioned in Section 2.1 are amenable to the degree achievement analysis, along the lines of the orginal GHKL treatment.

What is interesting is that many of the path-shape verbs are as well, including *descend, fall, drop, plummet, dive, raise, climb,* and *mount*. call these **vertical movement verbs**. In principle, vertical movement verbs are also amenable to a *zigzag*-type analysis. For example, we could define *descend* as a verb that just has a change function that returns the change in altitude for the entire event, without making use of a state function or INCREASE. Both analyses are possible. Which is right? Semantically there appears to be no difference.[25] I will continue to call a verb a degree achievement verb when the degree achievement analysis is possible.

The next question arising is whether vertical movement verbs have path as a state function or some degree-returning function expressing altitude. The answer is clearly a degree expressing function, on two counts:

(63) a. The Cessna rose/climbed/dropped more than the Piper Cub.

---

accomplishment as *widen* can:

(i) The roads zigzagged quite a bit in just 1000 meters.

The semantics in (34b) is consistent with this fact. It is consequence of the meaning of the degreeable predicate *zigzaggy* that a zigzagging event can be described with a telic property. Thus, we are not proposing a uniform decomposition of accomplishments (such as 'all accomplishments include the increase operator'), and it does not appear such a decomposition is possible, contra Dowty (1979).

[24]The verbs *dot*, *span*, *clutter* all seem to resist event readings. As far as I can tell, this just needs to be stipulated.

[25]Syntactic arguments for incorporated states work only for some degree achievements:

(i) The road widened again. [two readings]
(ii) The road rose again. [one reading?]
(iii) The temperature climbed again. [one reading.]

Thus (i) has two readings one which the road increases in size twice, another on which it simply returns to its previously wide state, but it seems to be difficult to get an analogous ambiguity for *rise* and impossible for *climb*.

b. The Cessna rose/climbed/dropped through the clouds.

First, what is being compared is altitude change, not something having to do with a part-whole comparison between paths. The *rise* version of (a) is true even if the Cessna ends up at a lower altitude than the Piper, as long as its total altitude change was greater. Secondly, *rise* and its ilk do not entail spreading motion.

There is another class of path-shape verbs, however, for which the degree achievement analysis is possible, but for which $\mathbf{path}_{\mathrm{T}}$ arguably IS the state function. These verbs which would have an analysis paralleling *extend* and the *cover* verbs, include *exit*, *emerge*, *leave*, and *enter*. Call these container-transition verbs. A first argument in favor of a path state function is graduality:

(64) a. The mountain gradually emerged from behind the clouds.
b. The crowd gradually entered/exited/left the auditorium.

Note that only event readings are possible, though both subjects, being extended, are eligible for extent readings:

(65) a. The mountain gradually narrowed at the summit.
b. The crowd gradually widened near the entrance to the piazza.

This follows the pattern with *cover* and *extend*. Also following the pattern of *cover* and *extend*, spatial accomplishments are not possible with container transition verbs:

(66) # The mountain emerged from the clouds in just a few hundred feet.

Finally, container transition verbs do not allow verbal comparatives, which is consistent with the kind of partial order path state functions give:[26]

(67) # The summit emerged from the mist more than the ridge.

[26]The only order path state functions give is mereological. Since the the summit region in (67) is not part of the ridge region, nor vice versa, no ordering relation between them exists. On the other hand, this sort of comparative:

(i) The summit emerged from the mist a bit more.

is much improved. Here we actually seem to be comparing spatial regions that DO stand in a part of relation, the mist covered summit region at time t and the mist-covered summit region at a later time t'.

All these facts are predicted if INCREASE cannot combine with $\mathbf{path}_S$, for reasons outlined in Section 4. On the other hand, if these verbs have a degree returning state function, INCREASE ought to combine with it, and the facts in (64), (66) and (67) would remain unexplained.

Another group of verbs displaying the same pattern of facts is the verbs from the *adorning* frame (12) that describe circular or enveloping motion, including *encircle, envelop* and *wreathe*.[27] Consider *encircle*:

(68) a. The soldiers gradually encircled the hill.[event reading only.]
b. The fog gradually encircled the hill. [no displacement motion entailed.]
c. # The soldier encircled the hill more than crowd.
d. ...

Another important dimension of a variation among extent predicates is whether the path is an incremental theme (Dowty 1991) in event readings; that is, do the truth conditions require that the path covered grow homomorphically with the event, with the location identified in the *from* phrase overlapped at the beginning of the event, and the location identified in the *to*-phrase overlapped at the end? We accounted for this difference in Section 3.3 by hypothesizing two distinct kinds of temporally-indexed paths $\mathbf{path}_T$ and $\mathbf{path}_T^S$, where $\mathbf{path}_T$ is the incremental path.

Vertical movement verbs manifest a possibility available in the analysis, but not discussed until now. They are degree achievements with incremental paths. In a path-phrase specifying sources and goals, the *from* phrase identifies the location of the lowest point in altitude and the *to*-phrase the location of the highest point. Accordingly, (69) is odd:

(69) ? The balloon rose from the ceiling to the floor.

This accords with the intuition, discussed in Section 3.3, that incremental path verbs are fundamentally verbs of movement.

Summarizing, then, on this analysis, extent verbs can vary in 3 ways:

[27] One could add *surround* tp this group. Note that to describe extent readings for these verbs, we need to assume a circular axis. This is a peculiar use of the word *axis*, but is consistent with our original formal definition of an axis simply as an ordered domain. Thus for example when using polar corrdinates to locate points in space the θ parameter or angle, is an axis in our sense. The necessary notion of axis for verbs such as *encircle* is something like *angle measured counterlockwise from some established line in some established plane* Then for any point in the plane we can determine θ. Then the pattern.

1. whether they can be defined in terms of INCREASE (extent *cover*, *extend*, and both versions of *zigzag* cannot);

2. whether their temporally indexed paths are incremental (**path**$_{\mathrm{T}}$ or **path**$_{\mathrm{T}}^{\mathrm{S}}$);

3. whether what is returned by the change function is a spatial region (*cover* and *extend*) or a degree (*widen*, *zigzag*)

The full array of possibilities for categorizing extent accomplishment predicates is shown in (70); in each cell, verbs above the horizontal line have incremental paths; verbs below it do not.

(70) **Categorization of extent accomplishment predicates**

range(Δ_e)		Degree Achievements	No INCREASE op
region, path	**path**$_{\mathrm{T}}^{\mathrm{S}}$	*cover, extend*	??
	path$_{\mathrm{T}}$	container transition verbs	??
degree	**path**$_{\mathrm{T}}^{\mathrm{S}}$	*widen*, *redden*, etc.	holistic path-shape verbs II
	path$_{\mathrm{T}}$	vertical movement verbs	holistic path-shape verbs I

Obviously, it is of interest that the upper right corner is empty.

The two “missing” verb classes with no state function, are described in (71)

(71) a. **Incremental path verb with no state function**:
   (1.) incremental path (event reading entails motion; extent reading does not);
   (2.) does not describe spreading motion (since that is an indicator of the INCREASE operator);
   (3.) lacks a verbal comparative (evidence for degree-range for Δ_e);
  b. **Non-incremental path verbs with no state function**:
   (1.) nonincremental path (neither reading entails incremental motion);
   (2.) does not describe spreading motion (since that is an indicator of the INCREASE operator);
   (3.) lacks a verbal comparative (evidence for degree-range for Δ_e);

A natural candidate for (71a) arises. There is no natural candidate for (71b), which appears to be an accidental lexical gap.

The natural candidate for (71a) is the verb *go*:

(72) a. The elevator went from the first floor to the penthouse in under ten seconds.
b. The cable went through 20 apartments in just 100 yards of horizontal distance.
c. # The elevator went more than the dumb waiter.

(72a) entails non-spreading motion with an incremental path and shows that *go* can be a temporal accomplishment; (72b) shows an extent reading that is a spatial accomplishment,

Suppose that *go* is just a change function which, applied to an event, returns its path:

(73) $\textbf{go}_{\mathrm{I}}(e) = \pi$ iff $\textbf{path}_{\mathrm{I}}(e) = \pi$

Paths have a natural mereological order[28], so this qualifies as a change function just as much as $\textbf{cover}_{\mathrm{S}}$ and $\textbf{extend}_{\mathrm{S}}$ do. Call this the **path-is-a-change-function** analysis. As with regions, it is a partial order, so we should not expect comparatives, so this fits very well into the upper right hand corner of (70). But is it right to say that *go* has no state function? Why can't π be the state-function?

Technically, according to the assumptions so far, it can't be, but that is only part of the story. According to the scheme underlying (70), an event state function component of a verb is a function of time Δ_t that defines the start and end states of an event, and the *difference* between those values of Δ_t is what is returned by INCREASE. The claim made by locating a verb in the upper right hand corner of (70) is that there are no well defined start and end states with a difference operation. Technically that is correct as we have used differences thus far.

Of course, paths return regions and even though the intrinsic ordering on regions is only partial, there is a very natural way to **define** a total difference operation on regions. It is called **distance**. So a state function treatment of *go* could be defined as follows:

(74) $\textbf{go}_{\mathrm{I}}(e) = d$ iff $\mathrm{DISTANCE}(\textbf{path}_{\mathrm{I}})(e) = d$

Call this the **path-is-a-state-function** analysis. On this view we would regard

28

$$\pi_1 \sqsubseteq \pi_2 \text{ iff } \mathrm{Dom}(\pi_1) \subseteq \mathrm{Dom}(\pi_2) \wedge \forall i \pi_1(i) = \pi_2(i)$$

DISTANCE as one of a family of INCREASE like operators[29], and we would be moving *go* into the lower left hand corner of (70). The argument against this view is that distances are ordered and we would expect verbal comparatives to work and they do not.

The view of gradual change that has been emerging in this paper is that change functions return two sorts of things, parts and degrees, partially ordered and totally ordered, respectively. As a matter of fact, the clear cases of totally ordered change measures, the adjectivally derived degree achievements, all allow verbal comparatives. It therefore seems quite natural to use this as a diagnostic for distinguishing **change by parts**, the top row of (70), from **change by degrees**, the bottom row. If this is right, *go* belongs in the top row and one of our missing verb classes is not missing.

Something like the analysis in (74) seems to be what Kennedy and Levin (2001) have in mind for all verbs of motion. One of the arguments for this path-is-a-state-function analysis is that verbal measure phrases, which also crop up with degree achievements, can be treated as simply filling the *change argument* position (that is, specifying what is returned by the change function). For example, *elevator went 300 feet* can be rendered:

$$\exists e[\text{DISTANCE}(\mathbf{path}_{\mathrm{T}})(e) = [300\text{ ft}] \wedge \textit{theme}(e) = elev\,]$$

However, on the path-is-a-change-function analysis advocated here the compositional semantics of this sentence looks the same; it's just that DISTANCE comes from the measure phrase or the construction introducing it instead of from the verb. This is presumably exactly like the semantic operation needed when combining mass nouns like *milk* with measure phrases like *two gallons*. It is also needed for *go* for speed measure phrases as well on either account. The main argument for the path-is-a-change-function account is that there is a principled account of the distribution of verbal comparatives.

A key point is the fact that there do seem to be verbs of motion that allow verbal comparatives, namely manner of motion verbs:

(75) a. John ran/walked/swam (a mile) more than Susan

[29] Note, however, that it is NOT simply an operation on pairs of points. It must be a function of the entire path, since it must compute path-distance rather than simply Euclidean distance between start and end points. It is true of one who has run exactly 4 revolutions around a quarter-mile oval that they have run a mile, and false that they have run 0 miles. Compare *rose one mile* or *fell one mile*, where the measure is really Euclidean distance along a vertical axis. This really can be a function of two points.

Here though there is a habitual reading paraphrasable as *ran/walked/swam more often*, there is also an eventive reading meaning *On that occasion John ran/walked/swam further than Susan*. For such verbs the path-is-a-state-function analysis seems correct.

But why should there be such a big difference between *walk* and *go*? The answer is that this big difference isn't so big. It's a rather minor syntactico-semantic fact about a word, not a deep semantic fact. The words *furniture* and *equipment* are mass nouns, yet they denote countable articles in the world. To count instances we need to insert classifier-like words like *pieces of* yielding phrases like *three pieces of furniture* and *three pieces of equipment*. We don't need to do this with words like *chair* and *tripod*, even though these are special cases of furniture and equipment. Similarly to form verbal comparatives with *go* we need an adverb that introduces a degree as in *John went (a mile) further than Sue.* Presumably, *far/further* introduces a DISTANCE operator into the semantics, just as distance measure phrases do.

Now consider **non-incremental path verbs with no state function**. The *abounding-with* frame of Framenet provides us with two verbs that satisfy all three criteria in (71b): *teem* and *crawl*.

(76) a. The waters of the bay teemed with fish from Pearson Point to the river mouth.
b. The basement crawled with ants from the coal scupper to the furnace.

The verbs *teem* and *crawl* have non-incremental paths, do not entail motion (in the relevant sense of displacement to a new location), do not entail spreading motion, and have no detectable verbal comparatives:

(77) a. # The waters of the bay teemed with fish more than the river delta.
b. # The basement crawled with termites more than the attic.

But they are not verbs that belong in the upper right hand corner of (70). They do not belong there because there is no sense in which they are either temporal or spatial accomplishments. They are states on both axes. They show no direct evidence of being accomplishments using frame adverbials:

(78) a. # The basement teemed/crawled with ants in 30 minutes. [frame adverbial reading]
b. # The basement teemed/crawled with ants in 50 yards.

And we saw in (19) that they are path-cumulative.

Thus one way of identifying the lexical gap is: there are no verbs that are like *teem* and *crawl* but are spatial accomplishments. Another way: there no verbs like *zigzag* and *go* but with non incremental paths on the event readings.

Finally a word about the relationship between spatial states and spatial accomplishments. it is a consequence of the analysis given above that spatial state predicate cannot be paired with a spatial accomplishment predicate via the INCREASE operator. [why there are no paired spatial states and accompllishments]

6 Dimensionality and change in lexical structure

We accounted for two aspects of aspectual variation, incrementality and graduality.

Since our discussion of incrementality basically concerned its effects on event readings, we can summarize our account by collecting together our event readings. This is done in (79):

(79)

Verb	Δ_e	Path	
zigzag	zigzaggy $\circ$ $path_{\mathrm{T}}$	$path_{\mathrm{T}}$	[+ Incr_e]
extend	$\mathrm{INCREASE}_{\mathrm{T}}(path_{\mathrm{T}})$	$path_{\mathrm{T}}$	
widen	$\mathrm{INCREASE}_{\mathrm{T}}(\mathbf{wide}^{\mathrm{S}}_{\mathrm{T}})$	$\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}$	[- Incr_e]
cover	$\mathrm{INCREASE}_{\mathrm{T}}(\mathbf{cover}^{\mathrm{S}}_{\mathrm{T}})$	$\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}$	

The account is that event readings with temporal paths will require incrementality of the path. All extent predicates allow spatial paths, but some also allow temporal paths. Since temporal paths can only occur on event readings, those predicates will have incremental paths on event readings.

The issue with graduality was the compatibility of *gradually* with certain predicates on their extent readings. We can summarize our account by collecting our extent readings. This is done in (80):

(80)

Verb	Δ_e	Δ_t	
widen	$\mathrm{INCREASE}_{\mathrm{S}}(wide_{\mathrm{S}})$	NA	[+ Grad $_e$] (degrees)
zigzag	zigzaggy $\circ$ $path_{\mathrm{S}}$	NA	
extend	NA	$\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}$	[- Grad $_e$] (parts)
cover	NA	$\mathbf{cover}^{\mathrm{S}}_{\mathrm{T}}$	

Our account is that predicates describing change by parts were not compatible with the INCREASE$_S$ operator and could only be spatially stative on their extent readings. This in turn was due to the fact that spatial paths return slices, which are not ordered with respect to each other, and do not provide state functions (Δ_ts) with the right sort of range for INCREASE to operate on.

We now show how the graduality facts can follow from a general characterization of verbs of gradual change, building on the ideas about mereologies of Section 4 [stuff moved from heer] The INCREASE operator does not apply to either version of *zigzag*. Why, for example, can't INCREASE$_T$ apply to *zigzag*$_T$ to produce a second-order version of *zigzag*, one which describes an event in which the degree of zigzaggyness changed?

The basic intuition is that it can't apply because a verb can have only one axis of change, and *zigzag* already has its one allowed axis of change. The formal reflex of this intuition is that INCREASE$_S$ must apply to functions from events to spatially indexed state functions and INCREASE$_T$ must apply to functions from events to temporally indexed state functions. That is, both apply to denotations approrpiate for states, 0-dimension predicates. The verb *zigzag*, on the other hand, denotes a function from events to degrees, a function appropriate for an accomplishment or activity, which returns a degree measuring the entire course of change in an event.

Summing up, non-triviality imposes a requirement defining gradual change, and that definition presupposes an axis of change. A verb can have only one axis of change. All the examples above where two axes are used are cases where one axis was the axis of reference and the second an axis of change. When events with change in two spatial dimensions have arisen (*cover*), I have described them with state functions whose values are surfaces. Thus the structure of the account is that there is always one independent variable, the axis of change, which can be mapped to a variety of domains some of them with multiple spatial dimensions.[30]

7 A conclusion

The results of this paper are essentially the following:

(a) Event and extent ambiguities can be accounted for with state functions whose domains may be either temporal or spatial indices;

[30]The description and terminology in this section follows many of the ideas of Jackendoff (1996), though I have departed somewhat from his usage, in not allowing two-dimensional predicates. Jackendoff allows what he calls two-dimensional predicates.

(b) Predicates with state functions that allow spatial indices are also predicates that allow spatial paths. Spatial indices require an oriented axis of the sort used elsewhere in the language of space, and spatial paths are the primary device for describing and evoking such axes;
(c) This establishes a domain of predicates with *spatial aspect*. Spatial aspect varies just as temporal aspect does. There are spatial operators that map spatial states to spatial accomplishments/activities;
(d) This has led to the proposal of a general characterization of verbs of gradual change: All verbs of gradual change have non-trivial change functions with mereologies as their ranges. This can be viewed simply as generalization of the degree hypothesis of HKL.
(e) There are two kinds of gradual change, change by degree and change by parts, with corresponding changes in the range of the state function. The ranges of the state functions of verbs of gradual change must be mereologies with remainders.

There is a natural way of generalizing the view of state functions explored here, which helps relate operators like INCREASE which operate over ordered domains with mereological structure, to operators like Dowty's 1979 BECOME operator, which accounts naturally for non-gradual change.

The point is this: All states, activities, accomplishments, and achievements may be viewed as having state-functions which obey the mereology axioms minus the Remainder Principle. To take this step would require admitting into the fold **Boolean** state functions for verbs of non-gradual change such as *solve*, *prove*, *give*, etcetera. The Boolean state function for *solve*, for example, is a function of time which returns FALSE for the entire temporal span of a solving event until the theme is solved. A Boolean domain is still ordered, and if we adopt

$$\text{FALSE} < \text{TRUE}$$

then the transition from non state to state will be an increase. Such a domain does not obey the Remainder Theorem, although the function does obey the non-triviality requirement, so this would be the essential structural difference between gradual change and non-gradual change. On this view, INCREASE and BECOME fall on a natural continuum.

This also opens up another possibility. The fact that there is no graduality with extent *cover*, no verb with the semantics

$$\text{INCREASE}_{\text{S}}(\text{cover}_{\text{S}})$$

as we saw in (52), may also be explained simply by saying there is no predicate with the meaning:

(81) cover_{S}.

That is, we could simply say that the state function in (81) is

not a legitimate state function for a natural language predicate to have. Thus there can be no stative adjective or verb which has (81) as its meaning because its range is trivial. Such functions arise only as steps in the definition of legitimate state functions like:

$$\text{cover}^{\text{S}}_{\text{T}},$$

which is nontrivial, and legitimate change functions like:

$$\text{INCREASE}_{\text{T}}(\text{cover}^{\text{S}}_{\text{T}}).$$

8 Change: Conclusion

Let us return to the starting point: descriptions of change require two ordered sets. Consider (82), repeating(20):

(82) The boiling point of water drops 3 degrees Fahrenheit between sea level and 4000 feet.

Points

A. zigzagy as defined here does now support the degree hypothesis.

This is because the degree of zigzaggyness is not an incremental participant. A subevent of an event of zigzagging may be more or less zigzaggy than the entire event. This in turn stems from the fact that we have not defined *zigzag* by means of the INCREASE operator. It bears no systematic relation to a function of instants of time, in contrast to *widen*.

John zigzagged three miles in 10 minutes.

a. John zigzagged more than Susan. b. John walked more than Susan.

a Does NOT entail he moved further. b does.

B. [not sure what this is about] zigzag may be telicized EITHER of two ways:

semelfactive? John zizgagged three times.in 10 minutes ?? John zigzagged three miles in 10 minutes

The reduction of change to states is not possible.

Let us review why this is with respect to the case of *zigzag*.

Notice the problem is NOT that one cant talk about zigzaggyness via a function of time. Calculus shows us how to define functions whose value at an instant of time is the rate of change at that moment in time. And it makes sense to talk about increases in this function, too! So the rate of change can be increasing (accelerating) and we can talk about the net increase between two moments of time:

$$\text{INCREASE}(\text{ZIGZAGGYNESS})(e) = q$$

The problem is that this isnt the right definition of the verb *zigzag*. The verb *zigzag* describes events with zigzaggy paths, not events of increase in zigzaggyness.

Conclusion: in a trivial sense, change presupposes states. But not in a semantically interesting sense. Change does not presuppose states that are independently motivated semantic components.

Other path shapes: scatter, dotted

Semelefactives as another example. Riddle [puncture many holes in]

Another blow to the idea of semantic structure.

Appendix

Definitions of path operators

The domain of any path function π is that set of points on the axis S that fall within e:

$$\textbf{path}_{\text{I}}(e) = \pi \quad \text{only if} \quad \pi : [\text{START}_{\text{I}}(e),\ \text{END}_{\text{I}}(e)] \rightarrow \text{Locations}$$

Loc is a function returning the entire spatial region covered by a path function, defined as:

$$\text{Loc}(\pi) = \bigsqcup_{s \in \text{Dom}(\pi)} \pi(s)$$

Temporal and spatial paths are defined by means of a location function AT, which returns the location of its argument at a time t:

(a)	**Spatial**	$\textbf{path}_{\text{S}}(e)(s)$	$=$	$\text{AT}(\text{theme}(e), \mathcal{T}(e)) \sqcap \text{plane}(s, \text{S})$
(b)	**Temporal**	$\textbf{path}_{\text{T}}(e)(t)$	$=$	$\text{AT}(\text{theme}(e), t)$
(c)	**Temporal Coercion**	$\textbf{path}^{\text{S}}_{\text{T}}(e)(t)$	$=$	$\text{AT}(\text{theme}(e), t) \sqcap \text{Loc}(\textit{path}_{\text{S}}(e))$

A key property is that path always returns a region of space, whether temporal or spatial; (a) Spatial path always returns the location of the theme at slice s within the temporal bounds of e ($\mathcal{T}(e)$); (b) Temporal path always returns the location of the theme at the relevant time within the spatial trace of of e ($\mathcal{S}(e)$).

All the aspectual differences between spatially and temporally indexed predicates then follow because temporal paths must overlap at successive moments of times, but spatial paths cannot overlap at successive spatial indices. The temporal coercion cases behave like temporal paths, only restricted by the the spatial path of the event.

I also assume a family of event-independent path functions incorporating spatial relations other than AT. These will be used, among other things, for the semantics of path prepositions like *into* and *onto*. As an example, the definition of *on*$_{\mathrm{S}}$ follows:

$$\textsc{on}_{\mathrm{S}}(x)(t)(s) = \ \textsc{on}(x,t) \bigsqcap \text{plane}(s, \mathrm{S})$$

The function ON is a spatial function returning the supporting surface region of its argument at a time t. Thus for each spatial index s, $\textsc{on}_{\mathrm{S}}(e)(s)$ returns the slice of the theme's supporting surface at s.

Mereologies

We take a mereology to be a join-semi-lattice in which the Remainder Principle is satisfied. The following definitions, in slightly modified form, are from Krifka (1998:199):

(83) $\mathrm{P} = \langle \mathrm{U_P},\ \oplus_{\mathrm{P}} \rangle$ is a **part-structure** iff

- (a) $\mathrm{U_P}$ is a set of entities;
- (b) $\oplus_{\mathrm{P}}$, the **sum (join) operation**, is a function from $\mathrm{U_P} \times \mathrm{U_P}$ to $\mathrm{U_P}$ that is idempotent, commutative, and associative.

From $\oplus_{\mathrm{P}}$ we may define 3 relations:

(84)
- (a) $\leq_{\mathrm{P}}$, the **part-of relation**, defined as $\forall x, y \in \mathrm{U_P}[x \leq_{\mathrm{P}} y \leftrightarrow x \oplus_{\mathrm{P}} y = y]$
- (b) $<_{\mathrm{P}}$, the **proper part-of relation** , defined as $\forall x, y \in \mathrm{U_P}[x <_{\mathrm{P}} y \leftrightarrow x \leq_{\mathrm{P}} y \wedge x \neq y]$
- (c) $\otimes_{\mathrm{P}}$, the **overlap relation**, defined as $\forall x, y \in \mathrm{U_P}[x \otimes_{\mathrm{P}} y \leftrightarrow \exists z \in \mathrm{P}[z \leq_{\mathrm{P}} y \wedge z \leq_{\mathrm{P}} x]\,]$

It is easy to show that $\leq$ is reflexive, transitive, and anti-symmetric. From the fact that $\oplus$ is idempotent, commutative, and associative it follows that $x \oplus y$ is an upper bound on x and y:

$$\begin{aligned} x \oplus (x \oplus y) &= (x \oplus x) \oplus y \\ &= x \oplus y \\ y \oplus (x \oplus y) &= y \oplus (y \oplus x) \\ &= (y \oplus y) \oplus x \\ &= y \oplus x \\ &= x \oplus y \end{aligned}$$

It is easy to show that $x \oplus y$ is a least upper bound as well. So this shows a part-structure is a join semi-lattice with ordering relation $\leq$ and join operation $\oplus$. Some authors (Pinon 1994a) simply use the term mereology to mean a part structure with the definitions in (84) added.

With Krifka, we use **mereology** to mean a part structure in which any ordered pair of ordered elements, x and y, has a unique *relative complement* r. That additional requirement is called the Remainder Principle:

(85) **Remainder (relative complement) principle:**

$$\forall x, y \in \mathrm{U_P}[x <_{\mathrm{P}} y \rightarrow \exists! r[\neg[r \otimes x] \wedge x \oplus z = y]]$$

As Krifka points out, structures that respect the Remainder Principle exclude bottom elements (elements that are less than all others), because everything overlaps with bottom, and the remainder axiom requires every non-maximal element have at least one non overlapping element. Thus sets of degrees must exclude 0. In order to satisfy these axioms, a set of degrees must also be closed under the difference operation.

Future research

Other kinds of change axes.

(86)

The temperature climbed.

The temperature climbed three degrees as he descended into the valley.

No “extent” reading for (a) Cumulativity requirement explains this.

References

Dowty, David. 1979. *Word Meaning and Montague Grammar*. Boston: Reidel.

Dowty, David R. 1991. Thematic proto roles and argument selection. *Language* 67:547–619.

Filip, Hana. 1999. *Aspect, Eventuality Types, and Nominal Reference*. New York: Garland.

Fillmore, Charles J. 1971. Santa Cruz lectures on deixis. Indiana University Linguistics Club. Also published as *Lectures on deixis*. 1997. California: CSLI Publications.

Fillmore, Charles J, and Collin Baker. 2000. FrameNet web site. `http://www.icsi.berkeley.edu/~framenet`.

Fong, Vivienne. 1997. A diphasic approach to directional locatives. In A. Lawson (Ed.), *Proceedings from Semantics and Linguistic Theory VII*, 135–150. Cornell University: CLC Publications.

Gawron, Jean Mark. 2005. Generalized paths. In *The Proceedings from the Fifteenth Conference on Semantics and Linguistic Theory: SALT XV*, Ithaca, New York. Cornell University, Department of Linguistics, CLC Publications.

Hay, Jennifer, Christopher Kennedy, and Beth Levin. 1999. Scalar structure underlies telicity degree achievements. In *The Proceedings from the Ninth Conference on Semantics and Linguistic Theory: SALT IX*, Ithaca, New York. Cornell University, Department of Linguistics, CLC Publications.

Jackendoff, Ray. 1996. The proper treatment of measuring out, telicity, and perhaps even quantification in english. *Natural Language and Linguistic Theory* 14:305–354.

Jackendoff, Ray S. 1990. *Semantic Structures*. Cambridge, MA: The MIT Press.

Kennedy, Christopher, and Beth Levin. 2001. Telicity corresponds to degree of change. In *75th Annual LSA Meeting*, Washington, D.C. Handout.

Krifka, Manfred. 1989. Nominal reference, temporal constitution and quantification in event semantics. In R. Bartsch, J. van Benthem, and P. van Emde Boas (Eds.), *Semantics and Contextual Expressions*. Dordrecht.

Krifka, Manfred. 1992. Thematic relations as links between nominal reference and temporal constitution. In I. A. Sag and A. Szabolcsi (Eds.), *Lexical Matters*, 29–54. Stanford, CA: CSLI Publications.

Krifka, Manfred. 1998. The origins of telicity. In S. Rothstein (Ed.), *Events and Grammar*, 197–235. Dordrecht: Kluwer Academic Publishers.

Matsumoto, Yo. 1996. Subjective motion in english and japanese verbs. *Cognitive Linguistics* 7:183–226.

Pinon, Christopher. 1994a. *A mereology for aspectuality*. PhD thesis, Stanford University.

Pinon, Christopher J. 1994b. Accumulation and aspectuality in polish. In *Proceedings of the North East Linguistic Society 24*, University of Massachusetts at Amherst. North Eastern Linguistics Society.

Pinon, Christopher J. 2000. Happpening gradually. In *BLS 26*. Berkeley Linguistics Society, University of California at Berkeley, Department of Linguistics.

Talmy, Len. 1996. Fictive motion and 'ception'. In P. Bloom, M. A. Peterson, L. Nadel, and M. F. Garrett (Eds.), *Language and Space*, Vol. 3. Cambridge, MA: MIT Press.

Tversky, Barbara. 1996. Spatial perspective in descriptions. In P. Bloom, M. A. Peterson, L. Nadel, and M. F. Garrett (Eds.), *Language and Space*, Vol. 3. Cambridge, MA: MIT Press.

Verkuyl, Henk. 1978. Thematic relations and the semantic representation of verbs expressing change. *Studies in Language* 2:199–233.

Verkuyl, Henk. 1993. *A theory of aspectuality*. Cambridge, UK: Cambridge University Press.

Zwarts, Joost. 2005. Prepositional aspect and the algebra of paths. In *Workshop on Event Structures in Linguistic Form and Interpretation*. http://semanticsarchive.net/.