Generalized Paths

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1 Introduction

- **Spatial predicates with both State and Event Readings** (Anderson 1977, Jackendoff 1990, 1996, Matsumoto 1996, Talmy 1996)

(1) a. The fog extended from London toward Paris. (the state reading is an **extent** reading (Jackendoff 1990))
b. Debris covered the outfield.
c. Water filled the glass.

(2) a. Fog *gradually* covered the city. (event reading only)
b. Fog covered the city *for 3 hours*. (extent reading only)

(3)

Snow	covered	the mountain
Figure	Extent Predicate	Ground

(4) *Extent predicates*

extend, *cover*, *fill*, *surround*, *clutter*, *dot*, *span*

(5) a. Boulders littered the valley floor (from the hut to the river).
b. Plastic shampoo bottles cluttered the single shelf in the cramped shower.
c. The bridge spanned a rocky canyon.
d. Smoke columned above the small chimney.

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- **Basic properties**

(6) a. Snow covered the mountain from the valley floor to the ridge.
b. Snow covered the mountain.

(7) *Path-shape verbs Fillmore and Baker 2000*
(a) The road zizagged up the hill. (extent reading only)
(b) The halfback zigzagged toward the goal line. (event reading only)

(8) 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

The Pattern

1. **Spatial Extension**: The figure in an extent reading is represented as *extended* over the entire path. Thus figures that cannot be extended through space in the required configuration (such as halfbacks) are disallowed.
2. , Path-shape verbs describe the global shape of the path whether the path is temporally extended or not. It is a class property that movement is incremental (as location i is occupied location $i-1$ is vacated). . For verbs like *extend* and *surround* movement must be spreading, and extended figures are required even on the event readings .
3. Thus although the requirement for extended figures can be relaxed on event readings, all motion verbs showing event/state ambiguities require spatially extended figures on the state readings.
4. Conclusion: The attribution of a spatial configuration over the entire path to an extended figure is a necessary feature of these state readings, perhaps the motivating feature of these constructions.

- Non-motion predicate cases: State readings that predicate change **Widen**

(9) a. The crack widened at the north gate. (State event ambiguity with an extended figure)
b. The crack widened from the tower to the north gate. (path argument)
c. Others with extent readings: narrow, warm, cool, rise, fall, darken, lighten, brighten, dim, grow color adjectives

Length versus Width

(10) a. The carpet strip widened in the den. (extent reading OK: "The portion of the carpet strip in the den was wider than elsewhere.")
b. The cable lengthened in the den. (extent reading out; can't mean: "The portion of the cable in the den was longer than elsewhere.")

(11) *State readings with change*
(a) The extent reading of (9a) claims that at some point in space the crack is wider than it was at an "earlier" point.
(b) The crack gradually widened at the north gate.

(12) *Spatial accomplishments and spatial activities*
(a) The crack widened nearly half an inch in ten meters.
(b) The crack widened for 100 yards.

(13) a. The crack widened five inches in five minutes.
b. The crack widened for several hours.

(14) *Lack of progressive*
(a) # The crack was being an inch wide. (# stative + progressive)
(b) # The crack was widening an inch at the north gate.(extent reading)

- A cluster of properties to be explained

(15) a. Why are the figures extended in space in extent readings?
b. Why does this phenomenon correlate with path modifiers?
c. These are statives. How do statives preserve aspectual properties?

- Plan of the Talk

1. **Change with respect to space**: Formalize the notion of change with respect to space through the use of **state-functions**
2. Illustrate with an account of degree achievement verbs and verbs of motion
3. Show how the 3 properties in (15) are accounted for

2 Spatial Axes as Change Dimensions

I argue that spatial axes are required to capture change with respect to space and that these are independently motivated for the language of space.

- Change requires an ordered set

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

(17)

Phenomenon	Range	Domain
Sentence (16)	Temperature	Altitude
Event Reading Extent Predicate	Locations	Time
Extent Reading Extent Predicate	Locations	Space points

(18) **An axis** is a set of colinear points with a well-ordering.

Diphasic Locatives

(19) a. the road (in)to Ukiah (Modeled on Fong 1997)
b. the road out of Ukiah
c. The road to Ukiah widens 5 feet at the wall.
d. The road from Ukiah narrows 5 feet at the mall.

(20) *Projective Prepositions*: *behind, in front of, above, below, beside, ahead of*

(a) The futon is behind/beside the chair. (canonical sides, *intrinsic*, Fillmore 1971, Tversky 1996)
(b) The futon is behind the boulder.(no canonical sides, contextual POV: *extrinsic*)

(21) *Axis of reference*
(a) The axis of reference goes through the ground
(b) The orientation of the axis of reference may be determined either by intrinsic features of the ground or extrinsically.

(22) *An Axis*

(a) *Let L be a spatial axis.* Choose a frame of reference that makes L the x-axis. L is thus represented as a set of coordinates of the form $\langle x, 0, 0, 0 \rangle$, where the last coordinate is time.

(b) *Let T be the time axis.*

(c) *plane*(s, S) is the set of points that project on to point s on axis S. For time, this is just the set of spatiotemporal points that are *at* a time.

(23) *Slices of an entity at an index*

(a) $\mathcal{T}(x)$ is the spatiotemporal trace of entity x

(b) The part of an entity x at an index s, spatial OR temporal

$$\text{slice}_{\text{S}}(x, s) = l \text{ iff } \mathcal{T}(x) \sqcap \text{plane}(s, \text{S}) = l$$

3 Degree Achievements

Summarizing the analysis of Hay, Kennedy, Levin (Hay et al. 1999, HKL).

1. An adjective like *wide* denotes a function from entities and times to degrees:[1]

$$[\![\text{wide}(e)(t)]\!] = \text{width}(\text{figure}(e))(t) = d$$

2. The verb *widen*

$$[\text{widen}_e \text{ by d -much}] = \text{difference}\circ\text{wide}(e){=}d$$

d is the *difference* argument, measuring the amount of change in e on the adjectival scale.

3. Difference

$$[\![\text{difference}\circ\text{wide}(e) = d]\!] = 1 \text{ iff}$$
$$\text{width}(\text{figure}(e))(\textsc{end}(e)) = \text{width}(\text{figure}(e))(\textsc{start}(e)) + d$$

[1] I have modified the analysis in HKL to introduce events at the level of adjectives. This addresses a problem in the original formulation of the INCREASE operator, which is where events first enter in:

$$[\![\textsc{increase}]\!](\text{G}(x))(d)(e) = 1\text{iff}\text{G}(x)(\textsc{end}(e)) = \text{G}(x)(\textsc{start}(e)) + d$$

If you run this definition right to left, it means that any event that starts when x's G-increase starts and ends when x's G-increase ends is an event of x G-increasing by d, which seems to render vacuous the introduction of events.

4. Our suggested revision: Make *wide* sensitive to what axis width is being measured on, temporal or spatial.

$$\text{difference}\circ\text{wide}_{\text{S}}(e){=}[.5\,\text{in}]$$

(24) *S is an axis*

(a) When spatial, S is an axis L determining the cross-sections whose widths are being measured; s is the L-coordinate of the cross-section.

(b) When temporal, S is the time axis, s is a time.

(25) a. The crack$_c$ widened half an inch.
b. Schematizing over both readings

$$\exists\, e\ \ [\text{difference}\circ\text{wide}_{\text{S}}(e){=}[.5\,\text{in}]\ \wedge\ \text{figure}(e){=}c\ ]$$

(26) *Start of an event along axis S*[2]

$$\textsc{start}_{\text{S}}(e)\ \ =\ \ \underset{p\in\mathcal{T}(e)}{\text{Min}}\ \ \text{coordinate}(S,\, p)$$

5. Yet to be shown (Section 5):

   (a) How *slice* and *wide* interact

   (b) how path expressions like those in (27) affect the truth conditions of the measurement in both event and extent readings

   (27) The crack widened from the north gate to the tower.

4 Analysis of motion predicates

Our next task is to extend the idea of change with respect to space into the domain of motion. To this end we need a function like *wide* from an event and an index to a domain where change can be tracked. But for motion we propose that the domain not be a *scale* (an ordered set with additions and differences) but simply an ordered set. This requires generalizing the notion of degree-function to what we will call a *state function*:

(28) *state-function*

A function from entities and indices on an axis to an ordered set.

[2] $\mathcal{T}(e)$ is Krifka's (1998) temporal trace function

4.1 Path

(29) *Definition of path operator*[3]

$$\text{path}_{\text{S}}(e){=}\pi \quad \text{iff} \quad \begin{array}{l} \pi : [\textsc{start}_{\text{S}}(e),\ \textsc{end}_{\text{S}}(e)] \rightarrow \text{Locations and} \\ \pi : \text{s} \mapsto \text{slice(figure}(e),\ s) \sqcap \mathcal{T}(e) \end{array}$$

In general, there are many starts and ends for an event e, and many path functions, depending on which axis through it is chosen.

path(e)(s):

(30) a. When s is a point s_0 on spatial axis L, $\text{path}_{\text{L}}(e)(s_0)$ is a slice of the figure of e defined over the time interval for which e is defined.
b. When s is a time t_0, $\text{path}_{\text{T}}(e)(t_0)$ is the location of the figure at time t_0.

(31) *A path-determined ordering on events:*

$$e_1 \sqsubseteq_{\text{S}} e_2 \quad \text{iff} \quad \text{path}_{\text{S}}(e_1) \subseteq \text{path}_{\text{S}}(e_2) \wedge e_1 \sqsubseteq e_2$$

Here $\subseteq$ is used for the natural ordering on functions. $f_1 \subseteq f_2$ iff $\text{Dom}(f_1) \subseteq \text{Dom}(f_2)$ and f_1 agrees with f_2 for every $x \in \text{Dom}(f_1)$.

4.2 Path in a motion verb

(32) a. *extend*:

$$\begin{array}{lll} \text{extend}_{\text{S}}e & \text{iff} & \exists\pi[\text{path}_{\text{S}}(e){=}\pi \wedge \text{spreading-path}(\pi)] \\ & \text{iff} & \text{spreading-path}{\circ}\text{path}_{\text{S}}(e) \end{array}$$

b. *zigzag*

$$\text{zigzag}_{\text{S}}(e) \quad \text{iff} \quad \text{zigzag-shape}{\circ}\text{path}_{\text{S}}(e)$$

(33) a. Mist_m zigzagged from the valley floor_v to the ridge_r

[3]The idea of representing paths through the use of functions from events to times to locations is anticipated in Verkuyl 1978. This view of paths can probably be thought of as a model for the algebraic axiomatization of paths in Krifka (1998). Crucially, since these paths are sets of pairs of indices and locations, natural orderings, adjacency, and overlap relations can be defined in terms of relations in time and space. A potential benefit of this model is that spatially circular paths (SCPs) can be modeled using the axioms for non-circular paths, because SCPs are not formally circular. The location repeats but the index does not.

b.

$$\exists e[\text{zizag}_{\text{S}} e \wedge \text{figure}(e){=}m \wedge [v:r] \circ \text{path}_{\text{T}}(e)]$$

Summary of degree achievement and motion verbs
(a) state functions
(b) indices that are either space or time
(c) when spatial we track slices of the figure along an axis.

5 Paths in Degree Achievements

(34) *Length versus Width revisited*

(a) The carpet strip widened in the den. (extent reading OK: "The portion of the carpet strip in the den was wider than elsewhere.")
(b) The cable lengthened in the den. (extent reading out; can't mean: "The portion of the cable in the den was longer than elsewhere.")

(35) *Why should this be?*

A necessary condition for basic spatial extent predicates is that they are axially cumulative.

(36) *Axial Cumulativity*[4] A property P is cumulative with respect to axis S iff

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

(37) *Long is not axially cumulative*

An event with a path in which a cable is 2 feet long summed with an event in which a cable is 2 feet long does not necessarily give an event in which a cable is 2 feet long. It may now be 4 feet long.

(38) *How we could make Long axially cumulative*

If we took two axial sections of the same length (two sections of boat that ran from stem to stern) we could of course sum them to an axial section of the same length, but we do not seem to conventionally cut boats up that way, nor any of the kinds of things of which length may appropriately be measured.

[4]Zwarts (2005) argues that cumulativity is the relevant concept for idfentifying 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 will use it with regard to telicity.

(39) *Why should* widen *take path arguments?*

Because width is a property that varies with cross-sections and path is the unique semantic component that captures change with respect to cross section.

(40) *Definition of wide*[5]

$$\text{wide}_{\text{S}}(e){=}\pi \quad \text{iff} \quad \begin{array}{l}\pi : \text{S} \rightarrow \text{Distances and} \\ \pi : \text{s} \mapsto \text{width} \circ \text{path}_{\text{S}}(e)(s))\end{array}$$

(41) *Immediate account of role of path expressions*

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

$$[\![\exists\, e,\, \pi\ [\text{wide}(e){=}\pi\ \wedge\ \text{increase}(\pi){=}[.5\,\text{in}]\ \wedge\ \text{figure}(e){=}c\ \wedge [\text{ng} : \text{t}] \circ \text{path}_{\text{S}}(e)]]\!]$$

(42) *Account of spatial aspect*

(a) Spatial accomplishments: *in + spatial interval* requires a **non axially-cumulative event property.**
(b) *widen* unlike *wide* is non axially cumulative.
(c) The crack widened three inches in 20 feet.

1. The path account explains path as a necessary semantic component in extent readings.
2. Uniformly captures the semantics of path expressions with *widen*:

$$[v : r] \circ \text{path}_{\text{S}}(e)$$

3. Capture aspectual properties of *widen*

6 Summary

1. A necessary condition on a property for having extent readings is that the property may be summed along an axis, more precisely, that it be axially cumulative.

[5] This assumes a basic width function mapping from spatiotemporal regions to degrees:

$$\text{width}(\text{L}_2,\, s) = d$$

The width of region s is d.Here we assume another axis L_2 also supplied by the ground, giving direction of width on the cross-section.

2. Configurarion and motion along an axis is constrained through a semantic component path.

3. Spatial change events have a natural ordering that allows a definition of quantized spatially properties (and an account of aspectual contrasts based on that).

4. *Cover* and *Fill* are both naturally analyzed as degree acheivement verbs with change functions that have natural maxima, following HKL.

(43) *Our original questions*

(a) Why are the figures extended in space in extent readings? *Because extent readings require properties that are axially cumulative, so the figure must be viewed as extended along an axis.*

(b) Why does this phenomenon correlate with path modifiers? *Path is the essential semantic operation for getting hold of successive cross-sections of a figure, whether temporal or spatial.*

(c) These are statives. How can statives preserve aspectual properties? *This is the case of predicates like* widen*;* widen *has exactly the same lexical semantic structure in event and extent readings. Extent readings are stative only in the sense that they have no temporal strcuture. But they still describe change.*

7 Conclusion: Generalized Paths

(1) Jackendoff (1996)

(a) Differ in assumptions and notation

(b) Many significant convergences

(c) For Jackendoff, extent readings are projections of an event along a spatial axis, preserving certain homomorphisms among participants.

(d) This is what my path functions do

(e) Jackendoff does not address degree achievement cases or the possibility of aspectual struture among spatial predicates, but the possibility of doing so within his framework is there.

(2) Within the class of extent predicates there is a subclass that can describe change with respect to space

(3) There is aspectual variation among states. States have aspectual structure (Figure 1)

(4) Change/state functions were the key to providing an understanding of this phenomenon: Predicates with senses that move seamlessly between temporal and spatial domain preserving aspectual structure.

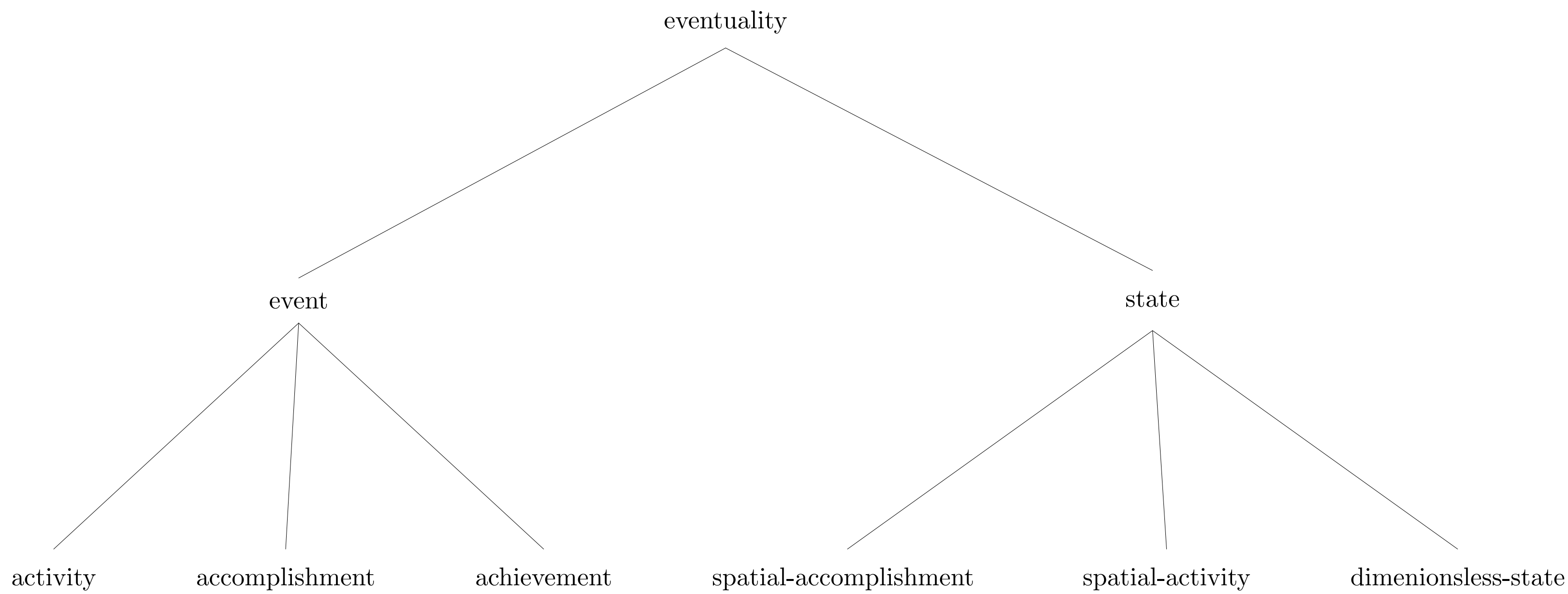

Figure 1: The classification of eventualities

Appendix: What motion is

Primitives in definition of path

plane(s, S)) is the region within e perpendicular to axis S that passes through point s:

$$\text{plane(L, } s) = \{\langle s, y, z, t\rangle \mid y, z, t \in \mathcal{R}\} \quad (1)$$

$$\text{plane(T, } s) = \{\langle x, y, z, s\rangle \mid x, y, z \in \mathcal{R}\} \quad (2)$$

- $[\![\text{run}_T]\!] = [\![\lambda e \exists \pi[\text{path}_T(e)=\pi \wedge \text{manner}(e)=\text{running}]]\!]$
- $[\![\text{zigzag}_S]\!] = [\![\text{zigzag-path} \circ \text{path}_S]\!]$
  A path function is a zigzag path iff it has many undifferentiable points and its slope often changes signs. So with a temporal range, this does entail motion.
- $[\![\text{extend}_S]\!] = [\![\text{spreading-motion} \circ \text{path}_S]\!]$
  A path function is a spreading motion path iff For all t_1, t_2, t_1, t_2 temporal indices, $\pi(t_1) \sqsubseteq \pi(t_2)$.
- $[\![[_V \text{ speed}_T]]\!] = [\![\text{speedy-path} \circ \text{path}_T]\!]$
  A path function is a speedy path iff it is a temporal path function with a high first derivative. So motion is entailed.
- $[\![[_V \text{ litter}_L]]\!] = [\![\text{littering-path} \circ \text{path}_L]\!]$
  A path function is a littering path iff it is a spatial path function with a highly discontinuous range. Motion disallowed.

Appendix:Semantics of path prepositions

Key idea: Path PP denote properties of path functions.

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

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