Paths and Scalar Change

Jean Mark Gawron
San Diego State University

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1 Introduction

- Event extent ambiguities

(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).

Event readings	(a)	An event of fog expansion took place over the indicated path.
	(b)	An event of crack widening took place over the indicated path (in the wall).
	(c)	An event of storm movement took place over the indicated path, which zigzagged.
	(d)	An event of snow movement took place, which covered the mountain over the indicated path.
Extent readings	(a)	The fog was configured so as to extend over the indicated path.
	(b)	The configuration of the crack was such that it widened if traced over the indicated path (in the wall).
	(c)	The configuration of the storm was zigzagging (over the indicated path).
	(d)	The snow was configured so as to to cover the mountain over the indicated path.

- Extent predicates

(2) **Path-shape verbs** (Fillmore and Baker 2000)

a. angle, ascend, bear, bend, climb, crest, crisscross, cross, curl, descend, dip, dive, drop, edge, emerge, enter, exit, fall, leave, meander, mount, plummet, reach, rise, round, skirt, slant, snake, swerve, swing, traverse, undulate, veer, weave, wind, zigzag
b. Smoke columned from the chimney. [Productivity with denominal shape verbs: the idea of spatial configuration.]

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

(4) **Spreading motion predicates**

a. Verbs from Jackendoff's 1990 list that are not path-shape verbs but which show event/extent ambiguities, such as *surround*, *cover*, and *extend*.
b. 1. The fog covered the peninsula. (spreading)
2. The fog extended from the pier to the point. (spreading)
3. The halfback/storm zigzagged to the goal line. (both)
4. The shadows/leaves fell to the courthouse steps.(both)

(5) **Extent degree achievements**
A class of degree-achievement verbs, including *narrow, warm, cool, rise, fill, darken, lengthen, lighten, brighten, dim, grow*, and all color adjectives (but not *cover*[!]). I will call these **extent degree achievements**.

- Talking points

1. Jackendoff's path generalization (Jackendoff 1990): Extent predicatestake path-phrase modifiers on both readings. (1)
2. Properties of locations
   a. Path-shape predicates: Onfigurations the objects take in space
   b. Degree achievements that can be thought of as properties of places or spatial regions (associated with a theme)

1.1 The Account in Gawron (2006)

Properties of locations: all extent predicates lexically select for something I'll call a **spatially indexed path**, which are path phrases not associated with motion

(6) Location sensitive measures

a. The door widens 1 cm from the top to the bottom.
b. The door is 37 cm wide from the top to the doorknob, (but 38 cm wide below that).[Figure 1]

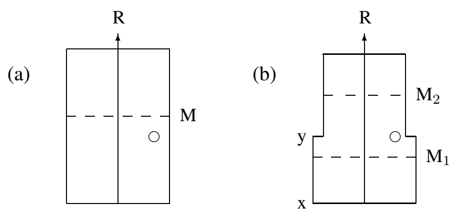

Figure 1: Measurement axis M and reference axis R for two doors; in (b), width measurement M_1 valid only from x to y

Incrementality: On event readings the reference axis sometimes coincides with the order in which change happens (7 [+ Incr]), and sometimes sometimes does not (7 [- Incr])

(7)

[+ 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

1.2 The previous analysis

1.2.1 HKL analysis

(Hay et al. 1999, Gawron 2006)

1. For HKL, adjectives are functions from time to degrees:

$$[\![\text{wide}]\!](t) = d : \text{ d a degree}$$

2. Eventizing this:

$$[\![\text{wide}]\!](\sigma)(t) = d$$

3. I will call $[\![\text{wide}]\!](\sigma)$ **a degree function**. A degree function is always a function from times to degrees.

4. The INCREASE operator used in the analysis of degree achievements produces a function from events to degrees:

$$\text{INCREASE}([\![\text{wide}]\!])(e) = d$$

I call such a function from events to degrees which measures the amount of change in an event a **change function**.

1.3 Gawron's analysis

Gawron (2006) needs to generalize HKL degree functions in two ways:

1. Needs to describe change with respect to space as well as time. So instead of functions from time, there are functions from **indices**, temporal or spatial. Time indices are points of time. Spaces indices are points along a spatial axis with respect to which objects are being oriented in space.

2. Needs functions returning not just degrees but objects in other ordered domains, regions and paths, in particular.

3. Call this generalized notion of degree function a **state function**.

(8) a. **State function** (Δ_t): A function from indices to an ordered domain (degrees, locations, etc.) measuring something at an index:

$$\begin{array}{lll} \Delta_t & [\![\text{wide}]\!](\sigma) & = \text{wide}^{\text{S}}_{\text{T}}(\sigma) \\ \Delta_t(s) & & = \text{wide}^{\text{S}}_{\text{T}}(\sigma)(s) = d \end{array}$$

b. **Change function** (Δ_e): A function from events to an ordered domain (measuring the amount of change that has taken place in the event):

$$\begin{array}{lll} \Delta_e & [\![\text{widen}]\!] & = \text{INCREASE}_{\text{T}}(\text{wide}^{\text{S}}_{\text{T}}) \\ \Delta_e(e) & & = \text{INCREASE}_{\text{T}}(\text{wide}^{\text{S}}_{\text{T}})(e) = d \end{array}$$

Analysis of extent predicates:

1. All extent predicates incorporate spatial paths, which require a pragmatically supplied spatial reference axis
2. Some extent predications exploit state functions evaluated at an index (*extend*, as in 1a) and (*cover*, as in 1c)
3. Some extent predications exploit change functions evaluating change over spatial axis, in particular, extent readings describing change along a spatial axis (*zigzag*, ain 1b) and (*widen*, as in 1c) require change functions whose domains are points on a reference axis.
4. Consequently, there are aspectual distinctions among extent readings

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

(10) Explanation of Jackendoff's Generalization
The **path** operator is the only semantic component available to introduce the spatial axis required for an extent reading, and path-phrases the only way to describe orientation of the axis.

To be provided today

1. An account of some of the variation in the aspectual nature of extent predicates, including the important case of cover/fill verbs as in (1d), unanalyzed in Gawron (2006).

The kind of degree-acheivement based analysis that works for *widen* does not work in all cases.

2. An proposal for how extent predicates fit in with a general account of state functions and telicity such as the one outlined in Kennedy and Levin (2001).

1.4 A diagnostic of aspectual structure

(11) **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.

(12) All the predicates in (11) 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.

A Generalization

(13) **Degreeability**

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

(14) **Two kinds of change**

a. **change by degrees**: the predicates in (13a) and (13b)
b. **change by regions**: the predicates in (13c) and (13d) (spreading motion)

(15) Insufficient to explain (11) simply by saying that *gradually* requires change by degrees, because this does not account for the fact that the non-degreeable predicates in (11) *do* combine with *gradually* on the event reading.

1.5 Preview of the account

Dimensionality (Jackendoff 1996)

(16) All extent readings are **stative**, but some, (1b) and (1c), describe change along a spatial axis.

Predicates that are both spatially and temporally static are **0-dimensional**.

Predicates that describe change along an axis (accomplishments or activities, spatial or temporal) are **1-dimensional**.

(17) **Two kinds of difference among verbs of change**

1. Spatially indexed change and temporally indexed change
2. Change by parts and change by degrees
3. The interaction with the aspect-changing operator INCREASE:

	Degrees	Regions
Temporal Indexing	INCREASE	INCREASE
Spatial Indexing	INCREASE	*

(18) Outline

(1) Introduction (this section)
(2) Analysis of *widen*: Change and spatial dimensions
(3) Change by region: *extend* and *cover*
(4) Graduality: Change by parts versus change by degrees
(5) Motivating aspectual variation: Change by region versus change by degrees
(6) Mereologies and scales in the account of change
(7) Conclusion

2 Degreeable predicates

2.1 Change by degrees: Widen

(19) Account of (1b) (1b) exploits a contextually provided spatial axis to measure out change. Path expressions select an interval on that axis.

(20) **Width is measured at an index i, which may be temporal or spatial**

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

Motivating contextually provided axes

(21) **Projective prepositions**(Fillmore 1971, Landau and Jackendoff 1993, Levinson 1996, Tversky 1996)

a. The ball is behind the chair. [intrinsic]
b. The ball is behind the rock.[relative]
c.

Intrinsic/Relative	Absolute
in front of/in back of	above/below
right/left	over/under
across (from)	on/under

(22) *Wide* exploits both intrinsic and relative spatial axes

a. The cabinet is 6 feet wide.[intrinsic]
b. The boulder is 6 feet wide. [relative]

(23)

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

Evaluation of a state function at a temporal index.

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

Bringing paths in

(25) Path operator and events

$\mathbf{path}(e)$ denotes the path function associated with event e

(26) a. **path**$_{\mathrm{T}}(e)(t)$: the location of the theme at time t.
b. **path**$_{\mathrm{S}}(e)(s)$: the location of the slice of the theme that intersects the plane through axis S at s.
c. **path**$^{\mathrm{S}}_{\mathrm{T}}(e)(t)$: the location of the theme at time t restricted to the region defined by the spatial path of e (6) [NB: a function of times thatr exploits an orthognal spatial axis S]

Claim: Extent predicates are properties of locations returned by the path function.

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

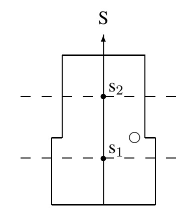

Figure 2: Indices s_1 and s_2, points on S, defining distinct slices (dashed lines), which are regions giving distinct width measurements

(28) a. The crack widened half an inch.
b. Event reading: $\text{increase}_\text{T}(\text{wide}^\text{S}_\text{T})(e) = [.5 \text{ in}]$
c. Extent reading: $\text{increase}_\text{S}(\text{wide}_\text{S})(e) = [.5 \text{ in}]$

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

(30) to be substituted the following into (29):

$$\begin{array}{c} \ldots \text{increase}_\text{I}(\text{wide}^\text{S}_\text{I})(e) = d \ldots \\ \ldots \text{START}_\text{I}(e){=}i_1 \wedge \text{END}_\text{I}(e){=}i_2 \ldots \\ \Longleftrightarrow \\ \ldots \text{START}_\text{I}(\sigma_1){=}i_1 \wedge \text{END}_\text{I}(\sigma_2){=}i_2 \ldots \end{array}$$

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

Aspectual Nature (cf. 9)

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

2.2 Zigzag

(33) a. *zigzag* is a degreeable predicate but does not describe change by degrees: Bounding the degree does not bound the change.
b. As with *widen*, the only change between event and extent readings, is a change of axis. There is no aspectual difference between the readings.

(34) zigzag: $\text{zigzag}_\text{I}(e) = \pi$ iff $\exists d\,[\text{ZIGZAGGY}_\text{I}(\pi) = d \wedge \text{path}_\text{I}(e) = \pi]$
$\text{zigzag}_\text{I} \sqsubseteq \text{path}_\text{I}$

(35) a. Mist_m zigzagged from the valley floor_v to the ridge_r
b. $\exists e, d, \pi[\text{zigzag}_\text{S}(e){=}\pi \wedge \text{theme}(e){=}m \wedge \text{zigzaggy}(\pi){=}d \wedge [v : r](\pi)]$

Degreeability

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

(37) a. I5 zigzagged more than I5 in that stretch.
b. Jones zigzagged more than Jim Brown that day.

Aspectual nature

1. The degree of zigzaggyness bears no homomorphic relation to the event. Informally:

$$e \leq e' \not\to \text{zigzaggyness}(e) \leq \text{zigzaggyness}(e')$$

(38) a. The road continued to widen (road must get wider further on).
b. The road continued to zigzag (road does not need to get zigzaggier)

2. Conversely path does

(39) a. The crack widened from the north gate to the tower for long minutes.
b. The halfback zigzagged from midfield to the goal line for seconds. (iterative only)

3. The denotation of *zigzag* in (34) includes no INCREASE operator and no state function (no function of moments of time).

4. The denotation of *zigzag* is a change function:

$$\text{zigzag}_\text{I}(e) = \pi$$

π is a measure of the change in the whole event (from an ordered domain).

(40) The road zigzagged quite a bit in 20 miles.

2.3 Change by region: Extend and Cover

(41) (a) $\text{extend}^{\text{S}}_{\text{T}}(\sigma)(t) = l$ iff $\exists\pi[\text{path}^{\text{S}}_{\text{T}}(\sigma) = \pi \wedge \pi(s) = l]$

$\text{extend}^{\text{S}}_{\text{T}} = \text{path}^{\text{S}}_{\text{T}}$

(b) $\text{extend}_{\text{T}}(e) = l$ iff $[\textsc{increase}_{\text{T}}(\text{path}_{\text{T}})(e) = l]$

An aspectual difference between the two readings

(42) a. The fog$_f$ extended from the valley floor$_v$ to the ridge$_r$

b. Extent reading:

$$\exists\sigma,\ \pi[\text{extend}^{\text{S}}_{\text{T}}(\sigma) = \pi \wedge \text{theme}(\sigma){=}f\ \wedge [v : r](\pi)]$$

c. Event reading

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

(43) a. **Ordering spatial regions**: $l_1 \sqsubseteq l_2$

b. **The relative complement of two ordered regions:**

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

(44) $\text{increase}(\text{extend})(e) = l$ iff $\exists\,\sigma_1,\ \sigma_2,\ l_1,\ l_2[\text{extend}(\sigma_1)(\textsc{start}(e)) = l_1 \wedge$
$\text{extend}(\sigma_2)(\textsc{end}(e)) = l_2 \wedge$
$l_1 + l = l_2]$

$d_1 + d = d_2$ iff $d = d_1/d_2$

(45) The bar extended to the wall. [Event reading]

$$l_{\text{start}} \sqsubseteq l_{\text{end}}$$

Extension to *cover* (also spreading motion)

(46) $\text{cover}_{\text{S}}(e) = \text{path}_{\text{S}}(e)$

Condition: $\text{cover-path}_{\text{S}}(e, \pi)$ where

$\text{cover-path}_{\text{S}}(e, \pi)$ iff $\text{Loc}(\textsc{on}_{\text{S}}(\text{goal}(e))(\mathcal{T}(e))) \sqsubseteq \text{Loc}(\pi)$

(47) $\text{cover}^{\text{S}}_{\text{T}}(e) = \text{path}^{\text{S}}_{\text{T}}(e)$

Condition: $\forall t \in \mathcal{T}(e)[\mathcal{G} \sqsubseteq \text{path}^{\text{S}}_{\text{T}}(e)(t)]$ where

$\mathcal{G} = \text{Loc}(\textsc{on}_{\text{S}}(\text{goal}(e))(\mathcal{T}(e)))$

(48) l: The region covered during the event:

$$\textsc{increase}_{\text{T}}(\text{cover}^{\text{S}}_{\text{T}})(e) = l$$
where
$$l = \text{cover}^{\text{S}}_{\text{T}}(\textsc{end}(e))/\text{cover}^{\text{S}}_{\text{T}}(\textsc{start}(e))$$

Aspectual nature

(49) The verb *cover* is not a degree achievement. The state function returns locations, not degrees. Other than that, however, it is like other degree achievements

2.4 Summarizing

(50) a. **State function** (Δ_t)

b. **Change function** (Δ_e)

(51)

Predicate	Δ_t	Δ_e
extend	path_{T}	$\textsc{increase}_{\text{T}}(\text{path}_{\text{T}})$
widen	$\text{wide}^{\text{S}}_{\text{T}}$	$\textsc{increase}_{\text{T}}(\text{wide}^{\text{S}}_{\text{T}})$
cover	$\text{cover}^{\text{S}}_{\text{T}}$	$\textsc{increase}_{\text{T}}(\text{cover}^{\text{S}}_{\text{T}})$
zigzag	NA	zigzag_{I}

(52) *zigzag*: an accomplishment with no state function (or INCREASE operator) The roads zigzagged quite a bit in just 1000 meters.

(53) **Aspect change**

Verb	Extent	Event	
widen	$\textsc{increase}_{\text{S}}(\text{wide}_{\text{S}})$	$\textsc{increase}_{\text{T}}(\text{wide}^{\text{S}}_{\text{T}})$	Uniform Aspect
zigzag	$\text{zigzaggy}_{\text{S}}$	zigzag_{T}	
extend	path_{S}	$\textsc{increase}_{\text{T}}(\text{path}_{\text{T}})$	Aspect Change
cover	$\text{cover}^{\text{S}}_{\text{T}}$	$\textsc{increase}_{\text{T}}(\text{cover}^{\text{S}}_{\text{T}})$	

(54) **Account of incrementality**(7)

Verb	Δ_e	Path	
zigzag	zigzag_{T}	path_{T}	[+ Incr$_e$]
extend	$\textsc{increase}_{\text{T}}(\text{path}_{\text{T}})$	path_{T}	
widen	$\textsc{increase}_{\text{T}}(\text{wide}^{\text{S}}_{\text{T}})$	$\text{path}^{\text{S}}_{\text{T}}$	[- Incr$_e$]
cover	$\textsc{increase}_{\text{T}}(\text{cover}^{\text{S}}_{\text{T}})$	$\text{path}^{\text{S}}_{\text{T}}$	

3 Graduality

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

(56) Extent *cover* is a 0-dimensional predicate (see 16)

1. # The snow covered 100 square miles of canyon in just 5 miles.
2. The snow covered the canyon in 5 minutes.
3. The crack widened an in inch in 5 yards.

(57)

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

(58) **A proposal for graduality**

a. The adverb *gradually* combines with predicate denotations $[\![\alpha]\!]$ that are change functions (verbs of gradual change), that is

$$[\![\alpha]\!](e) = d$$

where d is a measure of change in e.

b. *extend* and *cover* start out out as 0-dimensional predicates (Δ_t type denotations), therefore need to combine with INCREASE to become verbs of change.

c. Only their temporally indexed versions can do so.

Why?

A constraint on the kinds of algebras to which the increase operator may apply

(59) **Remainder principle** (Krifka 1998):
$\forall x, y \in \mathrm{U_P}[x <_{\mathrm{P}} y \rightarrow \exists! r[\neg[r \otimes x] \wedge x \oplus r = y]]$

(60) **Systems that satisfy the remainder principle**

a. Degrees on a scale. If $d_1 < d_2$, there is some minimal d such that

$$d_1 + d = d_2$$

This d does not overlap d_1.

b. For any set s, $\wp(\mathrm{s}) - \{\mathrm{s}, \emptyset\}$

c. **A mereology** is a part-whole structure. For example, Link's 1983 algebra of mass terms and plurals are both mereologies satisfying the remainder principle; so are locations under the sub-region relation. [1]

(61) **Temporal change by regions and Temporal change by degrees**

a. both cover$_{\mathrm{S}}$ and cover$^{\mathrm{S}}_{\mathrm{T}}(e)(t)$ take their ranges in the mereology of locations.

b. cover$_{\mathrm{S}}$ does so only trivially. No two elements in the range of cover$_{\mathrm{S}}$ are ordered because the range of cover$_{\mathrm{S}}$ is a set of disjoint slices.

c. Thus it is quite natural that INCREASE cannot apply to cover$_{\mathrm{S}}$.

d. On the other hand, as a predicate of spreading motion, cover$^{\mathrm{S}}_{\mathrm{T}}(e)$ must include spatially ordered regions. Thus it is quite natural that INCREASE can apply to cover$^{\mathrm{S}}_{\mathrm{T}}(e)(t)$.

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

4 A definition of gradual change

4.1 Verbs of gradual change

1. incremental theme verbs

(62) a. John ate *the bagel* (in 5 minutes).
b. Mary learned *the sonata* (in 5 days).
c. Beethoven wrote *a sonata* (in 5 days).
d. Alice mowed *the lawn* (in 5 minutes).
e. Bobbie Joe read *War and Peace* (in 5 days).

2. Zucchi (1998) argues that the aspectual ambiguities of a verb like *bake*, similar to those exhibited by degree acheivement verbs, may be accounted for assuming a degreeable predicate in the semantics.

(63) a. The soup cooled for 3 minutes (but was still too hot).
b. The soup cooled in 3 minutes

What's left (besides states)?

(64) Non-gradual change

a. repair the computer
b. prove the theorem
c. solve the Rubik's cube

(65) Two approaches to the account of aspectual properties of verbs of gradual change

a. Mereological accounts (Krifka 1989, Krifka 1992, Krifka 1998, Pinon 1994, Ramchand 1997, Filip 1999)
b. Degree-based account (Zucchi 1998, Hay et al. 1999, Kratzer 2000, Kennedy and Levin 2001, Beavers 2004, Wechsler 2005)

The Degree Hypothesis Kennedy and Levin (2001): Verbs of gradual change contain gradable properties as part of their meaning. Telicity is determined by the semantic properties of the degree of change.

(66) Verbs of gradual change have a change argument q: $\Delta_e(e) = q$

(67) Modification of degree hypothesis:

The change argument can be an element in a mereology.

(68)

Verb class	Example	Degree Account	Mereological Account
Verbs of motion	walk	Odometer distance traveled	Path
Verbs of consumption	eat	Volume left	Quantity of stuff left
Fill/cover Verbs	cover	Percentage of surface	Surface region

(69) **Verbs of gradual change**

α is a verb of gradual change iff there exists some mereology M such that

$$[\![\alpha]\!] \in \mathrm{M}^{\mathrm{E}}$$

and $[\![\alpha]\!]$ is **event dynamic** with respect to M; where an event function f is event dynamic with respect to M if and only if

(a)

$$\mathrm{Range}(f) \subseteq \mathrm{M};\ \text{and}$$

(b) Change in f nontrivial:

$$\forall x \in \mathrm{M},\ e \in \mathrm{Dom}(f), [f(e) = x \rightarrow \exists e' \sqsubset e,\ y \leq_{\mathrm{M}} x[\,\mathrm{f}(e') = y\,]\,]$$

(70) **Informal definition of a mereology** (see appendix)

(1) M is a join semi-lattice;
(2) M obeys the remainder principle (59)

(71) Examples

a. Masses of stuff under the consists-of ordering
b. Paths under the subpath ordering
c. Locations under the subregion ordering
d. Sets of degrees

Summarizing
1. *gradually* combines only with verbs of gradual change
2. INCREASE must produce verbs of gradual change. Therefore it cannot combine with a state function which is trivial by definition in the relevant mereology ($\mathrm{path}_{\mathrm{S}}$ in the mereology of locations).

5 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;
(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.

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:

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

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**	$\mathbf{path}_{\mathrm{S}}(e)(s)$	=	$\textsc{at}(\text{theme}(e), \mathcal{T}(e)) \bigsqcap \text{plane}(s, \mathrm{S})$
(b)	**Temporal**	$\mathbf{path}_{\mathrm{T}}(e)(t)$	=	$\textsc{at}(\text{theme}(e), t)$
(c)	**Temporal Coercion**	$\mathbf{path}^{\mathrm{S}}_{\mathrm{T}}(e)(t)$	=	$\textsc{at}(\text{theme}(e), t) \bigsqcap \text{Loc}(\text{path}_{\mathrm{S}}(e))$

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 figure at slice s within the temporal bounds of e ($\mathcal{T}(e)$); (b) Temporal path always returns the location of the figure 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_{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):

(72) $\mathrm{P} = \langle \mathrm{U_P},\ \oplus_{\mathrm{P}} \rangle$ 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:

(73) (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 $\forall x, y \in \mathrm{U_P}[x \otimes_{\mathrm{P}} y \leftrightarrow \exists z \in \mathrm{P}[z \leq_{\mathrm{P}} y \wedge z \leq_{\mathrm{P}} x]\,]$

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:

Remainder (relative complement) principle:
$\forall x, y \in \mathrm{U_P}[x <_{\mathrm{P}} y \rightarrow \exists! r[\neg[r \otimes x] \wedge x \oplus z = y]]$

Endnotes

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[1]Axioms for a mereology including the above remainder principle are presented in Krifka (1998:199), as adapted from Simons (1987), and are reproduced in the appendix.

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