Motion, Scalar Paths, and Lexical Aspect

Jean Mark Gawron
San Diego State University*

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1 Introduction

- **Spatial predicates with both State and Event Readings** (Anderson 1977, Jackendoff 1990, Talmy 1985, Matsumoto 1996)

(1) The fog extended from London toward Paris. (Call the state reading an **extent** reading)

- **Basic properties to be accounted for**

1. **Extent Readings:** State readings in which the figure, for example, *the fog* in (1), is extended through space. **Extended figures** include plurals as well.

   (2) Soldiers surrounded the city.(Jackendoff 1990, plural figure, event and state reading)

*San Diego State University, Department of Linguistics and Oriental Languages, BAM 321, 5500 Campanile Drive, San Diego, CA 92182-7717, gawron@mail.sdsu.edu.

2. **Path argument** available with these predicates, even when they are not motion predicates (Jackendoff 1990).

   (3) a. Snow covered the valley (from the road to the ridge).

   b. Fog blanketed the city (from the waterfront to Beacon Hill).

3. **Not Resultant States**

   (4) *Boulders covered the valley* $\not\rightarrow$ *There was a covering event in which boulders came to cover the the valley..*

4. **Many motion verbs do not show the ambiguity (manner of motion predicates)**

   (5) a. Boulders rolled across the valley.

   b. Water poured across the valley.

- Jackendoff's account captures basic facts by making the semantic property of spatial extent central

(6) Snow covered the hills.

(7) a. Extent reading of (6)

$$\left[\text{EXT } ([_{\text{Thing}} \text{ SNOW }], [_{\text{Path}} \text{ OVER } ([\text{HILLS}]) \,]) \right]$$

(8) a. Event reading of (6)

$$\left[\text{INCH} \left(\left[\text{ EXT } ([_{\text{Thing}} \text{ SNOW }], [_{\text{Path}} \text{ OVER } ([\text{HILLS}]) \,]) \right] \right) \right]$$

- **Generality of phenomenon**: Jackendoff's account is plausible for verbs like *cover*, *fill*, *extend*, whose core semantics is compatible with the EXTENT concept. But the phonomenon is more general.

1. **Path-shape verbs:** (Fillmore and Baker 2000) Jackendoff's account overgeneralizes the distribution of extended figures:

   (9) a. The road zigzagged to the summit. (extent reading, extended figure, as before)

   b. The halfback zigzagged to the goal line. (extent reading, no extended figure)

   c. angle,bear,bend,crest,crisscross, cross, 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

   (10)

   Jackendoff's event reading for (9b)

   $$*\left[{}_{\text{Event}}\ \text{INCH}\left(\left[{}_{\text{State}}\ \text{EXT}\ ([{}_{\text{Thing}}\ \text{HB}\ ],\ [{}_{\text{Path}}\ \text{TOWARD}([\text{GL}])\ ])\right]\right)\right]$$

2. **Incrementality of Paths:** There is a distinction among the paths that exhibit extent readings that Jackendoff's INCH operator does not capture. Some are **incremental**, some are not (for incrementality of paths, see Verkuyl and Zwarts 1992, Pinon 1993, Krifka 1998). Contrast (11) and (12).

(11) a. Fog gradually covered the bay from the point to the peninsula.

b. Event reading: Fog may materialize simultaneously over the entire extent of the bay. [consistent with Jackendoff's INCH account]

(12) a. Fog gradually extended from the point to the peninsula.

b. Event reading: Fog must move sequentially along a path which first intersects the point then reaches the peninsula. [not captured by Jackendoff's INCH account]

- **Degree achievements**: Extent readings not just limited to predicates motion. Other kinds of change as well.

(13) a. The crack widened at the north gate. (State reading involves an extended figure)

b. The crack widened from the tower to the north gate. (path arguments as well)

c. Others with extent readings: narrow, warm, cool, rise, fall, busy(traffic sense), dark, light, bright, dim, color adjectives

- Analysis of the problems:

  1. The fact that *extend* has incremental paths (12) suggests that it is fundamentally a motion predicate. But Jackendoff's account makes it stative.
  2. Path shape verbs also appear to be true motion verbs. Thus there is a large class of motion verbs that allow extent readings.
  3. Degree achievements also fit the analysis poorly because they, too, are event predicates.

- Conclusion: Abandon the idea that these readings are limited to fundamentally stative predicates.

- Problems that abandoning Jackendoff's account raises:

1. Jackendoff's account satisfactorily handled a class of stative reading by saying they belonged to fundamentally stative predicates. The question for us now is: How is it that these state readings are compatible with verbs that are fundamentally verbs of change?
2. Jackendoff accounted for the correlation of extended figures with extent readings by making EXTENT the key semantic component for extent readings. Having abandoned his account we now owe another explanation for the correlation. Note that in the case of path shape verbs, predicates that do not require extended figures on their event readings (9b), switch to predicates that do require them on their extent readings (9a).

- Plan of the Talk

1. Argue that the extent readings illustrated in (1)-(13) are all examples of predicates that can describe change with respect to space.
2. Proposal:

   2.1. **Change with respect to space**: Formalize the notion of change as change with respect to time or space through the idea of a Δ-function, which is a function tracking change in some state domain with respect to either space or time. Paths are Δ-functions that track change through a domain of locations. The verb *widen* invokes a Δ-function that tracks width change through a domain of distances.

   2.2. **Quantification over parts**: Explain the co-occurrence of extended figures with extent readings as a result of the fact that extent readings require quantifying over the different parts of the figure at different points in space.

2 Spatial Aspect

We argue that all of the stative extent readings discussed in section 1 are instances of change with respect to space.

2.1 Spatially indexed change with degree achievements

- *widen*

(14) a. The crack widened at the north gate. (Event and State readings)

b. The crack widened at 5'o'clock. (Degree Achievement Hay et al. 1999)

1. Event reading of (14a): At some point in time the crack is wider than it was at an earlier point.
2. State reading of (14a): At some point in space the crack is wider than it was at an "earlier" point.

Both readings are about change

1. The extent reading of (14a) is false if the crack is everywhere of uniform width. This reading describes a *change*. It is just that it is a change in space.
2. The extent reading of (14a) is still a state: If the extent is true at an interval of time, it is true of any subinterval. That is, although it predicates a property that is not homogenous with respect to space, it *is* homogenous with respect to time.
3. (14b) is not homogenous with respect to time.

[LONG: So I'm not denying that (14a) is a state/ I'm denying that the idea of a state is incompatible with the idea of change.]

- Spatial aspect

  Pass tests for (spatial) accomplishment

  (15) The crack widened nearly half an inch in ten meters.

  Pass tests for (spatial) activity

  (16) The crack widened for 100 yards.

  "Spatial" readings for *widen* preserve aspectual properties of temporal readings

  (17) a. The crack widened five inches in five minutes.

  b. The crack widened for several hours.

  "Spatial" readings for *zigzag* preserve aspectual properties of temporal readings

  (18) a. The road zigzagged a 30 mile path in 10 minutes as the crow flies.

  b. The missile zigzagged for thirty minutes.

  c. The missile zigzagged a 30 mile path in 10 miles as the crow flies.

  d. The road zigzagged for thirty miles.

- Aspectual persistence

  > Predicates have the same aspectual properties with extent readings as they do with event readings.

- Account of extent readings for degree achievements and path shape verbs should not include any "aspect" changing operators like Jackendoff's INCH.

2.2 Spatial change with motion predicates

- We have argued that extent readings for degree achievements involve "change in space". But there is no corresponding change apparent in extent readings for motion predicates like *extend*, *cover*, and *zigzag* (1), (3) and (9)

- Reminder: Extent readings involve extended figures:

  (19) The crowd extended from the steps to the edge of the square.

  In order (19) to be true, part of the crowd has to be located on the steps, part at the edge of the square, and part in some interval between.

- Parts of the figure change in some crucial aspect in both kinds of extent readings:

  1. Parts of the wall differ in width in (14a).
  2. Parts of the crowd differ in location in (19).

- Why extended figures:

  > Extent readings require a form of quantification over parts. A part of a single figure must manifest different properties at different places at a single time. Therefore the figure must be extended.

3 Analysis of motion predicates

Basic Idea

1. Paths will be functions from indices to locations that return the location of the figure at each index.

2. There are two kinds of paths

    2.1. **Spatially indexed paths:** functions from times to locations (the location of the figure at each time point)

$$\pi(t) = l$$

    2.2. **Temporally indexed paths:** functions from locations to locations (the location of parts of the figure with respect to a set of locations intersecting that of the figure):

$$\pi(s) = l$$

    We will refer to the spatial indices as "slices".

3. Paths for motion predicates will be defined by means of a *state-function*:

$$\begin{aligned}\text{PART-AT}(x, t, s) &= l \\ &\stackrel{\text{def}}{=} \text{AT}(x, t) \sqcap s\end{aligned}$$

    PART-AT(x, t, s): a function that gives the location of the part of x identified by some spatial slice s at time t.
    AT: a function from an entity and a time to that entity's location (*eigenplace function*, Wunderlich 1991)

4. In the next section we look at another kind of state-function, WIDTH, which can be used analogously to PART-AT, to track the state changes of a figure.

3.1 Motion Predicates

(20) a. The operator **path** relativizes the state function PART-AT to an event:

$$\mathbf{path} \stackrel{\text{def}}{=} \lambda e \lambda s_{\text{S}} \lambda t_{\text{time(e)}}[\text{PART-AT}(\text{figure}(e), t, s)]$$

Using S for a contextually provided set of spatial slices, time(e) for the time interval of e. The operator **path** is a partial function restricted to those sets.

b. Δ function: Applying **path** to an event e yields:

$$f = \lambda s_{\mathrm{S}}, \lambda t_{\mathrm{time}(e)}[\text{PART-AT}(\text{figure}(e), t, s)]$$

We call f the Δ function of e. [LONG: A Δ function tracks the change of the figure in an event with respect to some state space, here location.

c. Coercion operators to turn space-time state functions into either space or time functions:

temporally indexed:	$\mathrm{ti} = \lambda \mathcal{P} \lambda e \lambda t[\mathcal{P}(e)(\mathrm{loc}(e))(t)]$
	$\mathbf{path}_{\mathrm{T}} = \mathrm{ti}(\mathbf{path})$
spatially indexed:	$\mathrm{si} = \lambda \mathcal{P} \lambda e \lambda s[\mathcal{P}(e)(s)(\mathrm{time}(e))]$
	$\mathbf{path}_{\mathrm{S}} = \mathrm{si}(\mathbf{path})$

We will assume that coercion of two place path functions obligatory. Asserted change must always be with respect to either time or space.

d. Convention: We will use π to refer to a one-place path function, In the temporally indexed case:

$$\pi = \lambda s_{\mathrm{S}}[\text{PART-AT}(\text{figure}(e), \text{time}(e), s)]$$

- **Assumption: Operator $\mathbf{path}_{\mathrm{T}}$ correlates with motion**

  A predicate allows a temporally indexed path if and only if it expresses motion.

- **Operator $\mathbf{path}_{\mathrm{S}}$ correlates with spatial extent and spatial change**

(21) **What the spatial change is:** Each of the parts of the figure selected by an index s must be at a (potentially) different location.

(22) a. Fog$_f$ extended from the valley floor$_v$ to the ridge$_r$

b. Event Reading (over time)

$$\exists e, f[\text{extend}(e) \wedge \text{figure}(e){=}f \ \wedge \text{path}(e){=}f \ \wedge [v:r]_{\leq}(ti(f))]$$

This is equivalent to:

$$\exists e, \pi[\text{extend}(e) \wedge \text{figure}(e){=}f \ \wedge \text{path}_{\text{T}}(e){=}\pi \ \wedge [v:r]_{\leq}(\pi)]$$

Here $[v:r]_{\leq}$ designates a property of paths true if they begin at v and end at r and $\leq$ designates the usual order on times used to determine the beginning and ending of the path function.

c. Extent Reading (over space)

$$\exists e, \pi[\text{extend}(e) \wedge \text{figure}(e){=}f \ \wedge \text{path}_{\text{S}}(e){=}\pi \ \wedge [v:r]_{\preceq}(\pi)]$$

Here $\preceq$ designates a specific order on the set of spatial indices S imposed by context.

d. Many predicates lexically specified for path$_{\text{T}}$ (*roll*). No extent readings.

3.2 Semantics of path prepositions

- Key idea: Path prepositions don't really fill the path argument role. They just constrain the path function

- Therefore they are properties of of 1-place path functions:

(23) $[\![\text{from Boston}]\!]_R = \lambda\pi[\textsc{min}_R(\pi) \circ \text{Boston}]$
$= \lambda\pi[\,[\text{Boston} : \quad]_R(\pi)]$
= a property true of a path if the minimal member of its domain with respect to R overlaps Boston

- Composition with a two-place path function requires the intervention of a coercion operator:

(24) $[\![\text{from Boston}]\!] \circ \text{si}(\mathbf{path})(e)$

A spatial ordering available in context

(25) a. The road from Ukiah to Boonesville widens at the mall.

b. The road from Boonesville to Ukiah narrows at the mall.

3.3 Path Incrementality and Extended Figures

- In this section we show that two of the key properties of motion verbs with extent readings, path incrementality and extended figures with extent readings, are flip sides of one coin. Incrementality is a consequence of the definition of a temporally indexed change; extended figures are a consequence of the definition of spatially indexed change.

- **Incrementality**:

(26) $\exists e, \pi[\text{extend}(e) \wedge \text{figure}(e){=}f \wedge \text{path}_{\text{T}}(e){=}\pi \wedge [v : r]_{\leq}(\pi)]$

The definition of temporal path operator path_{T} together with minimality and maximality requirements of *from* and *to* require figure to move incrementally from v to r over the time interval of the event.

- **Extended figures**: The definition of path_s requires there to be a single figure that must be located at a set of places at a single time. Therefore, the figure must be extended.

3.4 Lexical Semantic Example: Path Shape and Manner of Motion Verbs

1. Underspecification

   - Some motion verbs are lexically specified for 2-place path functions (space and time).
   - Example: *zigzag*. The coercion operators **ti** and **si** allow it to have either extent or event readings. The requirement is that it can have no semantic component that refers to change in time.
   - Define an operator, trajectory, that applies to *2-place path functions*.

     $$\text{trajectory} = \lambda f \bigsqcup_{s,t} f(s,t)$$

     Intuition: gathers together the spatial trace of the figure's path function. *This concept of a trajectory is neutral between spatial and temporal indexing.*
   - Lexical semantics of *zigzag*:

     $$\text{zigzag}(e) \text{ iff zigzag-shape} \circ \text{trajectory} \circ \text{path}(e)$$

     This composition guarantees *zigzag* is defined for the *path* operator, making it compatible with both extent and event readings.
   - *Zigzag-shape* may be thought of as a dynamic property: Certain properties of the curve (first derivative) must undergo abrupt "changes" over its arc.

- *Zigzag* (and the other path shape predicates) may naturally be underspecified with respect to whether those changes are in time or in space because trajectory shape properties are not inherently linked to time.

2. In contrast we have manner of motion verbs like *roll*. *Roll* is a verb of motion which does not have extent readings and must therefore lexically specify a temporally indexed path:

$$\text{roll}(e) \text{ iff } \exists\pi\,[\text{path}_{\text{T}}(e){=}\pi \;\wedge \text{manner-of-motion}(e, \text{rolling})]$$

   $\text{path}_{\text{T}}(e){=}\pi$ entails motion (and change with respect to time). Again this seems to be natural given the meaning. For rolling to obtain some part of the figure or all of the figure must be rotating on a surface. Rotation is a property that can only be defined as a change in time, not a spatial configuration.

3. Jackendoff's problem: overpredicting extent readings

   - Consider (9b) again, repeated here:

     (27) The halfback zigzagged to the goal line.

     Jackendoff's account incorrectly predicts that (27) should have an extended figure.

   - Our account correctly predicts extended figures for extent readings but makes no such claim for event readings. (Section 3.3)

4 Degree Achievements

In this section we show that the idea of change with respect to space generalizes naturally to degree achievements.

1. *widen* will have a Δ functions that tracks change in widths. [LONG:

2. Simplify discussion by omitting path PPs at first. We refer to *half an inch* in (a) as the **difference expression**]

(28) a. The crack$_c$ widened half an inch.

b. Temporally indexed reading (f a function from space and time to widths):

$$\exists\, e, f$$
$$[\text{widen}(e) \wedge \text{figure}(e){=}c \;\wedge \text{width-state}(e){=}f \;\wedge\; \text{difference}(\text{ti}(f)) = [.5\,\text{in}]]$$

[LONG: We refer to f, the value of width-state for e, as e's Δ function. Parallel to our treatment of $\mathbf{path_T}$, we may define $\mathbf{width\text{-}state_T}$[1] and we have equivalently:]

$$\exists\, e, g$$
$$[\text{widen}(e) \wedge \text{figure}(e){=}c \;\wedge \text{width-state}_{\text{T}} = g \;\wedge\; \text{difference}(g) = [.5\,\text{in}]]$$

c. Spatially indexed reading

$$\exists\, e, f$$
$$[\text{widen}(e) \wedge\; \text{figure}(e){=}c \;\wedge \text{width-state}_{\text{S}}(e){=}f \;\wedge \text{difference}(f) = [.5\,\text{in}]]$$

3. Analogies of width-state and path:

	Motion	**Width**
state domain	locations	distances
Δ-function	$S \times T \mapsto S$	$S \times T \mapsto \text{Dist}$
underlying state function	PART-AT(x,s,t)=l	width(x,s,t)=d
relation of Δ function to event	path	width-state
expression constraining Δ function	path PP	difference expression
coercion operations	si, ti	si, ti

Both path PPs and difference expressions constrain a Δ function (rather than filling a Δ function argument). Both may require a coercion to do so.

[1]See Appendix for definition of the difference operator.

LONG: The relation *width-state* is a re lation between an eventuality and Δ function.

The relation *width-state* is the denotation of the adjective *wide*. Next we illustrate this and sketch how the adjective and verb can be systematically related along the lines of Hay et al. (1999).

4. We show how path expressions are licensed for both the adjective and verb.

4.1 Truth-conditional analysis of the adjective

The location is a critical component of a width measurement

(29) a. The crack was an inch wide at the north gate.

b. The crack was an inch wide from the north gate to the tower.

Partitivity:

> A state property S may have spatially indexed readings only if S can be a property of part of the figure without being a property of the figure as a whole.

width versus length: Partitive versus holistic

(30) a. The boat was 10 feet wide at the bow.

b. # The boat was 10 feet long at the bow.

The adjective denotation (generalizing the idea of Kennedy (1999))

(31) a. $\text{width}(x, l, t) = d$

State function: The width of x at time t and place l is d

b. We next define an operator that relativizes this ‘state function to an eventuality ϵ (state or event), parallel to what we did for PART-AT and path:

$$\text{width-state} \stackrel{\text{def}}{=} \lambda\epsilon\lambda s_{\text{S}}\lambda t_{\text{loc}(\epsilon)}.\text{width}(\text{figure}(\epsilon), \text{path}_{\text{S}}(\epsilon)(s), t)$$

A relation between an eventuality and a Δ function.

c.

$$[\![\, [_{\text{Adj}}\text{wide}] \,]\!] = \text{width-state}$$

d. The crack$_c$ is an inch wide from the north gate$_g$ to the tower$_t$.

$$\exists\sigma[\text{width-state}(\sigma, s, t) = [1\,\text{in}] \wedge \text{path}_S(\sigma){=}\pi \wedge \text{figure}(\sigma){=}c \wedge [\text{g:t}]_{\preceq}(\pi)]$$

The adjective semantics evaluates **width-state** at some indices s and t (s,t to be bound by context). In this case, the definition of **width** requires s to fall within the spatial interval [g:t].

4.2 Truth-conditional semantics of widen

- **The analysis of degree adjectives in Kennedy (1999) and degree achievements in Hay et al. (1999) (HKL)**

  1. HKL define an operator Increase that relates a scalar adjective meaning to the derived degree adjective verb.
  2. Turns a stative meaning into an event meaning
  3. Adds the *difference* argument of the above example.

- Idea

Underlying the meaning of both the adjective and the related verb is a function **width-state**. For the adjective we evaluate that function at an index; for the verb we relate it to a difference value.

- **Modified increase operator**

(32) a.

$$\text{increase} = \lambda f \lambda e[\text{positive} \circ \text{difference} \circ (\text{R}(f))(e)]$$
$$\text{R} \in \{\text{ti, si, I}\}$$

Takes a relation between eventualities and state functions and returns a property of eventualities

b. widen $= \text{increase(width-state)}$
$= \lambda e[\text{positive} \circ \text{difference} \circ \text{R(width-state)}(e)]$

4.3 Path Expressions and degree achievements

- **The verb *widen* is defined only for spatial paths on both event and extent readings**: [Long: Definition of **width-state** in] (31b).

(33) a. The crack$_c$ gradually widened from the north gate to the tower.

b. Event reading: no movement required of the crack. Widening can proceed uniformly along entire extent of a pre-existing crack.

c. **Path** $_{\text{T}}$ is still being reserved for motion.

- Claim: All predicates with extent readings incorporate **Path** $_{\text{S}}$ into their semantics, either by coercion (as with ambiguous motion verbs) or by definition (as with *widen*).

- This claim is not a logical necessity of the account. There could be a predicate like *widen* defined using:

$$\text{width-state}^* \stackrel{\text{def}}{=} \lambda \epsilon \lambda s \lambda t.\text{width}(\text{figure}(\epsilon), s, t)$$

instead of **width-state**. However, this would be an a location sensitive adjective that didn't have any way of constraining the location.

4.4 Summarizing degree achievement analysis

- Form of the account

  1. Ordinary scalar stative adjectives denote relations between states, times and degree intervals
  2. Location-sensitive adjectives denote relations between states, spaces, times, and degree intervals.
  3. Degree achievement verbs denote relations between state functions, differences, and events. In some cases, the Δ function is underspecified as path functions were and in those cases a predicate will have both event and extent readings.

5 Analysis and Consequences

5.1 Summary of analysis

1. A necessary condition for having extent readings is that a predicate can describe change with respect to space

2. Change with respect to space is constrained through a path role compatible with spatially indexed paths.

3. A necessary condition on that in turn is that a core semantic component of the predicate be a state sensitive to the location of different parts of the figure.

   1. With path-shape predicates that location-dependent state is a path shape property (e.g., *zigzag-shape*), whose truth conditions depend on the entire spatial trace of the figure's path.

2. With degree achievement verbs the state is a scalar adjective predicate, which must exhibit partitivity, that is, it must reference a measurement that can take different values for different parts of the figure.

5.2 Review of our questions

1. Why are extent readings available for predicates that express change?

   Extent readings *require* change, but change with respect to space. Predicates that have both event and extent readings are underspecified as to whether they express change with respect to space or time.

2. Why do extent readings correlate with extended figures?

   Extent readings refer to an ensemble of parts that must be at different locations at a single interval of time, so the figure must be extended.

5.3 Conclusion

- It was illuminating to think of the path role as functional:

  1. It gave us a natural way to capture extent readings.
  2. It gave us natural machinery for capturing the fact that some predicates seem to be underspecified for whether the change they describe is temporally indexed or temporally indexed.
  3. It gave us a natural device for generalizing the account from motion to another domain.

- The idea of Δ functions seems to be illuminating.

1. They are entirely consistent with a mereological approach. Thinking of functions extensionally:

   $$f \sqsubseteq g \text{ iff } f \subseteq g$$

   They may be thought of as models for axiomatic characterizations of path (Krifka 1998).

2. They lend themselves naturally to characterization of perspectival lexical differences. For example, the difference between different valences of load-spray verbs, linked to different choices of incremental theme in Dowty (1991), might derived frim the choice of Δ function, specifying whose change is being tracked with respect to what.

3. Some events will have Δ functions; some will not. In particular, achievements, true state transition predicates like *break* and *reach*, will not. Thus the property of having a Δ function carves up eventualities in a way that cross cuts telicity. The decisive property:

   > Whether a predicate describes a continuous change or a discontinuous change

   There are ways in which verbs of continuous change behave alike. In particular lexical ambiguities that cross-cut the telicity distinction often maintain the continuous change properties of a verb.

   1. activity/accomplishment ambiguities of degree acheivements
   2. activity/accomplishment ambiguities of verbs like *bake* (Zucchi 1998)
   3. event/extent ambiguities we have discussed today.

Appendix

5.4 Definition of difference

$$\text{difference}_{\mathrm{R}} \stackrel{\text{def}}{=} \lambda f.\iota\, d[d = \max_{\mathrm{R}}(f) - \min_{\mathrm{R}}(f)]$$

As with path expressions, maxima and minima are being taken relative to some given ordering, R.

5.5 Example lexical Semantics

5.5.1 Verbs of Motion

- $[_{\mathrm{V}}$ zigzag $]$

$$\text{zigzag}(e) \text{ iff zigzag-shape} \circ \text{trajectory} \circ \text{path}(e)$$

Implied operators/arguments of *zigzag*

Operator/Argument	**why defined**
path$_{\mathrm{S}}$	Definition of *zigzag*
figure	Definition of **path**$_{\mathrm{S}}$

- $[_{\mathrm{V}}$ roll $]$

$$\text{roll}(e) \text{ iff } \exists\pi \text{path}_{\mathrm{T}}(e){=}\pi\ \wedge \text{manner-of-motion}(e, \text{rolling})$$

Implied operators/arguments of *roll*

Operator/Argument	**why defined**
path$_{\mathrm{S}}$	Definition of *roll*
figure	Definition of **path**$_{\mathrm{S}}$

- $[_{\mathrm{V}}$ extend $]$

$$\text{extend}(e) \text{ iff increase(path)}(e)$$

Implied operators/arguments of *extend*

Operator/Argument	why defined
path$_{\mathrm{s}}$	Definition of *increase*
figure	Definition of **path**$_{\mathrm{s}}$

5.5.2 Degree achievements (including *fill* and *cover*)

- We begin by abstracting out the operation that will be used for all all location-sensitive degree achievement verbs, which we call Δ_s (s for scalar):

$$\Delta_s \stackrel{\text{def}}{=} \lambda\mathcal{P}\lambda\epsilon\lambda s_{\mathrm{s}}\lambda t_{\mathrm{loc}(\epsilon)}.\mathcal{P}(\text{figure}(\epsilon), \text{path}_{\mathrm{s}}(\epsilon)(s), t)$$

- $[_{\text{Adj}}\ \text{wide}\,]$

$$\begin{aligned} [\![\, [_{\text{Adj}}\text{wide}] \,]\!] = \ & \text{width-state} \\ & = \Delta_s(\text{width}) \\ & = \lambda\epsilon\lambda s_{\mathrm{s}}\lambda t_{\mathrm{loc}(\epsilon)}.\text{width}(\text{figure}(\epsilon), \text{path}_{\mathrm{s}}(\epsilon)(s), t) \end{aligned}$$

Implied operators/arguments of *wide*

Operator/Argument	why defined
path$_{\mathrm{s}}$	Definition of *width-state*
figure	Definition of **path**$_{\mathrm{s}}$

- $[_{\text{V}}\ \text{widen}\,]$

$$\begin{aligned} \text{widen} &= \text{increase}(\text{width-state}) \\ &= \lambda e[\text{positive} \circ \text{difference} \circ \text{R}(\text{width-state})(e)] \end{aligned}$$

Implied operators/arguments of *widen*

Operator/Argument	why defined
width-state	Definition of *widen*
difference	Definition of *increase*
path$_{\mathrm{s}}$	Definition of *width-state*
figure	Definition of **path**$_{\mathrm{s}}$

- $[_{\text{Adj}}\,\text{full}\,]$: we assume a basic location-sensitive measure function:

$$\text{fill}_0(x, s, t) = d$$

Degree interval d is the degree to which x fills space s at time t . This scale has a maximum we will call Max_{full}

$$\begin{array}{c}[\![\, [_{\text{Adj}}\text{full}]\,]\!](\sigma) \text{ iff } \exists s, t\, \text{full}(\sigma)(s)(t) \\ \text{where} \\ \text{full} = \lambda e \lambda s \lambda t[\Delta_s(\text{fill}_0)(\sigma)(s)(t) = \text{Max}_{\text{full}} \wedge \\ \text{in}(s, \text{container}(\sigma))\,]\end{array}$$

Implied operators/arguments of *full*

Operator/Argument	why defined
container	Definition of *full*
$\textbf{path}_{\text{s}}$	Definition of Δ
figure	Definition of $\textbf{path}_{\text{s}}$

- $[_{\text{V}}\,\text{fill}\,]$:

$$\begin{aligned}\text{fill} &= \text{increase(full)} \\ &= \lambda e[\text{positive} \circ \text{difference} \circ \text{R} \circ \text{full}(e)]\end{aligned}$$

Implied operators/arguments of *fill*

Operator/Argument	why defined
container	Definition of *full*
difference	Definition of *increase*
$\textbf{path}_{\text{s}}$	Definition of Δ
figure	Definition of $\textbf{path}_{\text{s}}$

- $[_{\text{V}}\text{cover}]$:

$$\begin{aligned}\text{cover} &= \text{increase(cover-state)} \\ &= \lambda e[\text{positive} \circ \text{difference} \circ \text{R} \circ \text{cover-state}(e)]\end{aligned}$$

where

$$\begin{array}{c}\text{cover-state} = \lambda e \lambda s \lambda t[\Delta_s(\text{fill}_0)(\sigma)(s)(t) = \text{Max}_{\text{full}} \wedge \\ \text{on}(s, \text{container}(\sigma))\,]\end{array}$$

So the difference between *fill* and *cover* is that for *cover* there is no adjective denoting its underlying state function, and also that the state involves an *on* relation where *full* requires an *in*-relation. **Implied operators/arguments of *cover***

Operator/Argument	why defined
container	Definition of *cover*
difference	Definition of *increase*
$\mathbf{path}_{\mathrm{s}}$	Definition of Δ
figure	Definition of $\mathbf{path}_{\mathrm{s}}$

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