Dynamic Interval Temporal Logic

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CS 112
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Outline

- Pustejovsky and Moszkowicz (2011)
- Capturing the Dynamics of Event Semantics
- Events are Programs initiating and tracking Change
- Distinguish the operational semantics of path and manner verbs
- Mani and Pustejovsky (2012)
- Use mereotopological relations to distinguish distinct manner verbs

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Manner Expressions
  run, walk, swim, amble, fly
- Orientation Path+Manner Expressions
  climb, descend
- Topo-metric Path Expressions
  approach, near, distance oneself
- Topo-metric orientation Expressions
  just below, just above

Path and Manner Motion Predication

m: manner, *p*: path

(1) a. The ball rolled$_m$.
    b. The ball crossed$_p$ the room.

(2) a. The ball rolled$_m$ across the room.
    b. The ball crossed$_p$ the room rolling.

Motion Predication in Languages

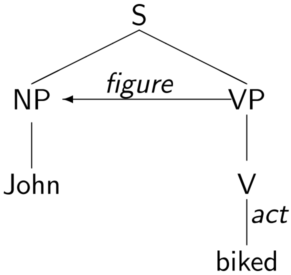
- Manner construction languages
  Path information is encoded in directional PPs and other adjuncts, while verb encode manner of motion
  English, German, Russian, Swedish, Chinese
- Path construction languages
  Path information is encoded in matrix verb, while adjuncts specify manner of motion
  Modern Greek, Spanish, Japanese, Turkish, Hindi

Defining Motion (Talmy 1985)

(3) a. The *event* or situation involved in the change of location ;
b. The object (construed as a point or region) that is undergoing movement (the *figure*);
c. The region (or *path*) traversed through the motion;
d. A distinguished point or region of the path (the *ground*);
e. The *manner* in which the change of location is carried out;
f. The *medium* through which the motion takes place.

Manner Predicates

(4)



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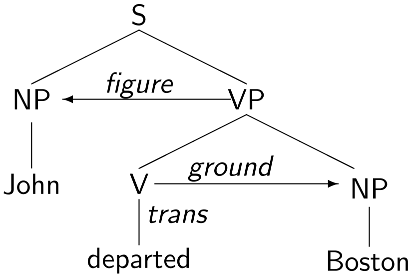
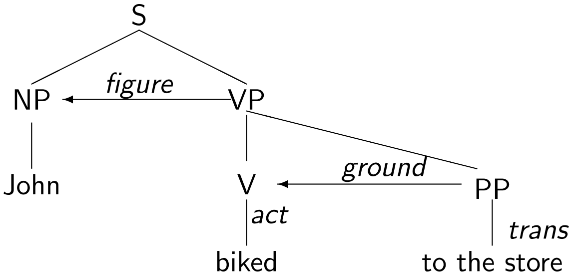


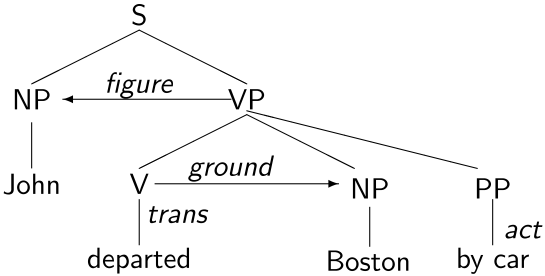
Manner with Path Adjunction

(6)



Path with Manner Adjunction

(7)



Need for Conceptual Modeling

- Lexical semantic distinctions are formal stipulations in a model, often with few observable correlations to data.
- Path verbs: arrive, leave, enter.
  - aspect
  - PP modification
- Manner verbs: drive, walk, run, crawl, fly, swim, drag, slide, hop, roll
  - aspect
  - adverbial modification

Simulations as Minimal Models

- Theorem proving (essentially type satisfaction of a verb in one class as opposed to another) provides a "negative handle" on the problem of determining consistency and informativeness for an utterance (Blackburn and Bos, 2008; Konrad, 2004)
- Model building provides a "positive handle" on whether two manner of motion processes are distinguished in the model.
- The simulation must specify *how* they are distinguished, demonstrating the informativeness of a distinction in our simulation.

Region Connection Calculus (RCC8)

(8) a. Disconnected (DC): A and B do not touch each other.
b. Externally Connected (EC): A and B touch each other at their boundaries.
c. Partial Overlap (PO): A and B overlap each other in Euclidean space.
d. Equal (EQ): A and B occupy the exact same Euclidean space.
e. Tangential Proper Part (TPP): A is inside B and touches the boundary of B.
f. Non-tangential Proper Part (NTPP): A is inside B and does not touch the boundary of B.
g. Tangential Proper Part (TPPi): B is inside A and touches the boundary of A.
h. Non-tangential Proper Part Inverse (NTPPi): B is inside A and does not touch the boundary of A.

Region Connection Calculus (RCC-8)

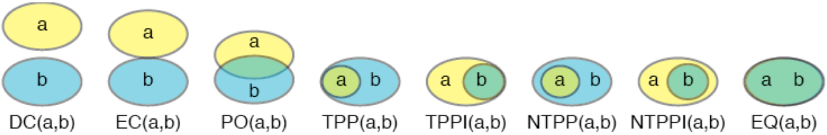
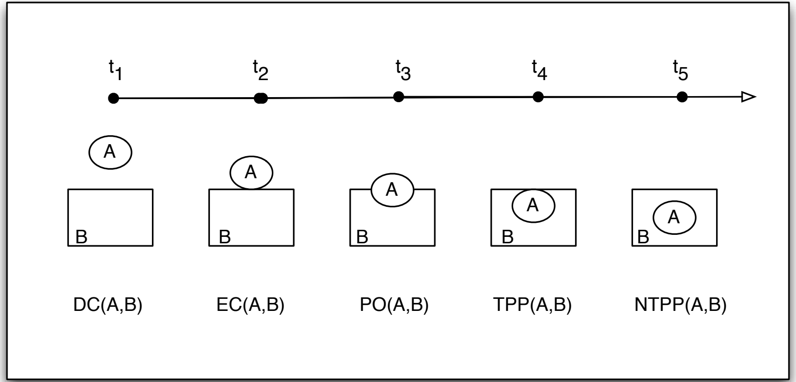


Figure 3.1: RCC-8 Relations Depicted in Two Dimensions

Galton Analysis of enter in RCC8



Linguistic Approaches to Defining Paths

- Talmy (1985): Path as part of the Motion Event Frame
- Jackendoff (1983,1996): GO-function
- Langacker (1987): COS verbs as paths
- Goldberg (1995): way-construction introduces path
- Krifka (1998): Temporal Trace function
- Zwarts (2006): event shape: The trajectory associated with an event in space represented by a path.

Subatomic Event Structure

(9) a. EVENT $\rightarrow$ STATE | PROCESS | TRANSITION

b. STATE: $\rightarrow$ e

c. PROCESS: $\rightarrow$ $e_1 \ldots e_n$

d. TRANSITION$_{ach}$: $\rightarrow$ STATE STATE

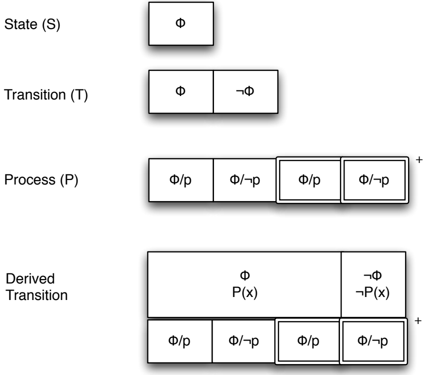
e. TRANSITION$_{acc}$: $\rightarrow$ PROCESS STATE

Pustejovsky (1991), Moens and Steedman (1988)

Dynamic Extensions to GL

- Qualia Structure: Can be interpreted dynamically
- Dynamic Selection: Encodes the way an argument participates in the event
- Tracking change: Models the dynamics of participant attributes

Frame-based Event Structure



2nd Conference on CTF, Pustejovsky (2009)

Dynamic Event Structure

- Events are built up from multiple (stacked) layers of primitive constraints on the individual participants.
- There may be many changes taking place within one atomic event, when viewed at the subatomic level.

Dynamic Interval Temporal Logic

(Pustejovsky and Moszkowicz, 2011)

- Formulas: ϕ propositions. Evaluated in a state, s.
- Programs: α, functions from states to states, $s \times s$. Evaluated over a pair of states, (s, s').
- Temporal Operators: $\bigcirc\phi$, $\Diamond\phi$, $\Box\phi$, $\phi\,\mathcal{U}\psi$.
- Program composition:
  1. They can be ordered, $\alpha;\beta$ (α is followed by β);
  2. They can be iterated, a^* (apply a zero or more times);
  3. They can be disjoined, $\alpha \cup \beta$ (apply either α or β);
  4. They can be turned into formulas
     $[\alpha]\phi$ (after every execution of α, ϕ is true);
     $\langle\alpha\rangle\phi$ (there is an execution of α, such that ϕ is true);
  5. Formulas can become programs, $\phi?$ (test to see if ϕ is true, and proceed if so).

Capturing Motion as Change in Spatial Relations

Dynamic Interval Temporal Logic

- Path verbs designate a distinguished value in the change of location, from one state to another.
  The change in value is tested.
- Manner of motion verbs iterate a change in location from state to state.
  The value is assigned and reassigned.

Labeled Transition System (LTS)

The dynamics of actions can be modeled as a Labeled Transition Systems (LTS).

An LTS consists of a 3-tuple, $\langle S, Act, \rightarrow \rangle$, where

(10) a. S is the set of states;
b. Act is a set of actions;
c. $\rightarrow$ is a total transition relation: $\rightarrow \subseteq S \times Act \times S$.

(11) $(e_1, \alpha, e_2) \in \rightarrow$

cf. Fernando (2001, 2013)

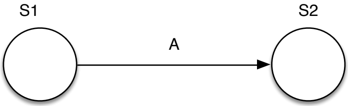
Labeled Transition System (LTS)

An action, α provides the labeling on an arrow, making it explicit what brings about a state-to-state transition.

As a shorthand for

(12) a. $(e_1, \alpha, e_2) \in\rightarrow$, we will also use:

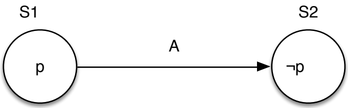
b. $e_1 \xrightarrow{\alpha} e_3$



Labeled Transition System (LTS)

If reference to the state content (rather than state name) is required for interpretation purposes, then as shorthand for: $(\{\phi\}_{e_1}, \alpha, \{\neg\phi\}_{e_2}) \in \rightarrow$, we use:

(13) $\boxed{\phi}_{e_1} \xrightarrow{\alpha} \boxed{\neg\phi}_{e_2}$



Temporal Labeled Transition System (TLTS)

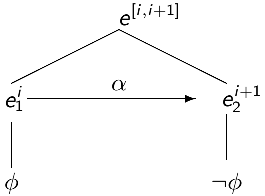
With temporal indexing from a Linear Temporal Logic, we can define a Temporal Labeled Transition System (TLTS). For a state, e_1, indexed at time i, we say $e_1@i$.

$(\{\phi\}_{e_1@i}, \alpha, \{\neg\phi\}_{e_2@i+1}) \in \rightarrow_{(i,i+1)}$, we use:

(14) $\boxed{\phi}_{e_1}^{i} \xrightarrow{\alpha} \boxed{\neg\phi}_{e_2}^{i+1}$

Basic Transition Structure (Pustejovsky and Moszkowicz, 2011)

(15)



(16) $x := y$ (ν-transition)
"x assumes the value given to y in the next state."
$\langle \mathcal{M}, (i, i+1), (u, u[x/u(y)]) \rangle \models x := y$
iff $\langle \mathcal{M}, i, u \rangle \models s_1 \wedge \langle \mathcal{M}, i+1, u[x/u(y)] \rangle \models x = y$

(17)

$$\begin{tikzcd}
 & e^{[i,i+1]} \arrow[dl, dash] \arrow[dr, dash] & \\
e_1^i \arrow[rr, "x := y"] \arrow[d, dash] & & e_2^{i+1} \arrow[d, dash] \\
\mathcal{A}(z) = x & & \mathcal{A}(z) = y
\end{tikzcd}$$

Processes

With a ν-transition defined, a *process* can be viewed as simply an iteration of basic variable assignments and re-assignments:

(18)
$$
\begin{array}{c}
e \\
e_1 \xrightarrow{\nu} e_2 \; \ldots \; \xrightarrow{\nu} \; e_n
\end{array}
$$

Directed Motion

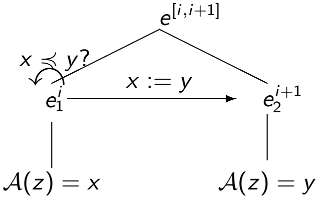
(19) $\overset{\overset{x \neq y?}{\curvearrowleft}}{\boxed{loc(z) = x}}_{e_1} \xrightarrow{\nu} \boxed{loc(z) = y}_{e_2}$

When this test references the ordinal values on a scale, $\mathcal{C}$, this becomes a *directed ν-transition* $(\vec{\nu})$, e.g., $x \preccurlyeq y$, $x \succcurlyeq y$.

(20) $\vec{\nu} =_{df} \overset{\overset{\mathcal{C}?}{\curvearrowleft}}{e_i} \xrightarrow{\nu} e_{i+1}$

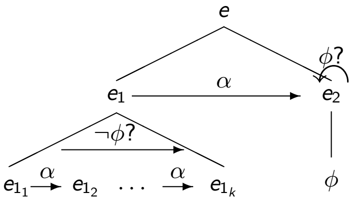
Directed Motion

(21)



Accomplishment Event Structure (Paths)

(22)



(23) MOTION LEAVING A TRAIL:

a. Assign a value, y, to the location of the moving object, x.

$loc(x) := y$

b. Name this value b (this will be the beginning of the movement);

$b := y$

c. Initiate a path p that is a list, starting at b;

$p := (b)$

d. Then, reassign the value of y to z, where $y \neq z$

$y := z, y \neq z$

e. Add the reassigned value of y to path p;

$p := (p, z)$

e. Kleene iterate steps (d) and (e);

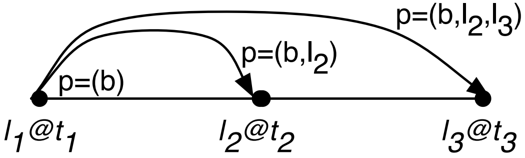


Figure: Directed Motion leaving a Trail

(24) a. The ball rolled 20 feet.
$\exists p \exists x[[roll(x,p) \wedge ball(x) \wedge length(p) = [20, foot]]$
b. John biked for 5 miles.
$\exists p[[bike(j,p) \wedge length(p) = [5, mile]]$

Generalizing the Path Metaphor to Creation Predicates

Pustejovsky and Jezek 2012

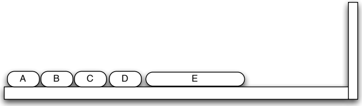
Accomplishments are Lexically Encoded Tests.

John built a house.

- Test-predicates for creation verbs
- build selects for a quantized individual as argument.
- $\lambda \vec{z} \lambda y \lambda x[build(x, \vec{z}, y)]$

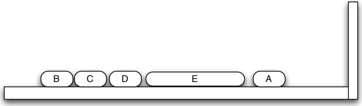
- An ordinal scale drives the incremental creation forward
- A nominal scale acts as a test for completion (telicity)

Incremental Theme and Parallel Scales



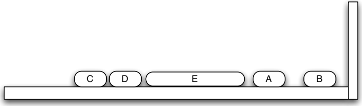
- Mary is building a table.
- Change is measured over an **ordinal scale**.
- Trail, τ is null.

Incremental Theme and Parallel Scales



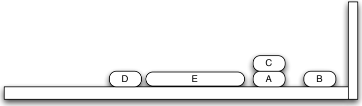
- Mary is building a table.
- Change is measured over an **ordinal scale**.
- Trail, $\tau = [A]$.

Incremental Theme and Parallel Scales



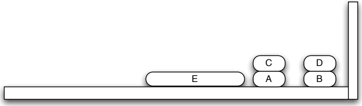
- Mary is building a table.
- Change is measured over an **ordinal scale**.
- Trail, $\tau = [A, B]$

Incremental Theme and Parallel Scales

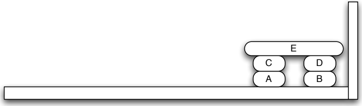


- Mary is building a table.
- Change is measured over an **ordinal scale**.
- Trail, $\tau = [A, B, C]$

Incremental Theme and Parallel Scales



- Mary is building a table.
- Change is measured over an **ordinal scale**.
- Trail, $\tau = [A, B, C, D]$



- Mary built a table.
- Change is measured over a **nominal scale**.
- Trail, $\tau = [A, B, C, D, E]$; $table(\tau)$.

Accomplishments

(25) a. John built a table.

b. Mary walked to the store.

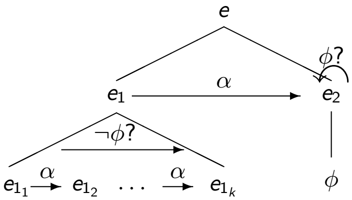
$build(x, z, y)$	$build(x, z, y)^+$	$build(x, z, y), y = v$
$\neg table(v)$		$table(v)$

$_{\langle i,j \rangle}$

Table: Accomplishment: parallel tracks of changes

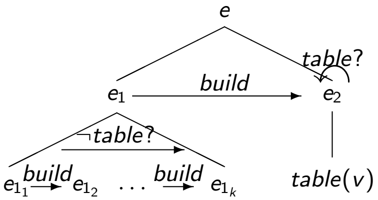
Dynamic Event Structure

(26)



Parallel Scales define an Accomplishment

(27)



Mereotopological Distinctions in Manner

Differentiating meaning within manner verbs
Mani and Pustejovsky (2012)

For Figure (F) relative to Ground (G):

- EC(F,G), throughout motion:
- DC(F,G), throughout motion:
- EC(F,G) followed by DC(F,G), throughout motion:
- Sub-part(F',F), EC(F',G) followed by DC(F',G), throughout motion:
- Containment of F in a Vehicle (V).

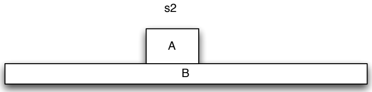
Bouncing and Hopping

$$(28) \quad \overset{\neg DC(x,G)?}{\boxed{loc(z) = x}}_{e_0} \xrightarrow{\vec{\nu}} \overset{DC(x,G)?}{\boxed{loc(z) = y_1}}_{e_1} \xrightarrow{\vec{\nu}} \overset{\neg DC(x,G)?}{\boxed{loc(z) = y_2}}_{e_2}$$

Sliding Action

- The box slides across the floor.
- $[\![slide]\!]=$
  $\langle[\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 1]@s_2, [\partial A \cap \partial B = 1]@s_3\rangle$;

Sliding Action



- The box slides across the floor.
- $[\![slide]\!] =$
  $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 1]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle$;

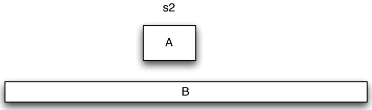
Sliding Action

- The box slides across the floor.
- $[\![slide]\!]=$
  $\langle[\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 1]@s_2, [\partial A \cap \partial B = 1]@s_3\rangle$;

Hopping Action

- The box hops across the floor.
- $\langle[\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 0]@s_2, [\partial A \cap \partial B = 1]@s_3\rangle$;

Hopping Action



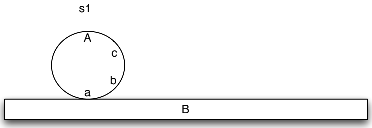
- The box hops across the floor.
- $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 0]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle$;

Hopping Action

- The box hops across the floor.
- $\langle[\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 0]@s_2, [\partial A \cap \partial B = 1]@s_3\rangle$;

Rolling Action

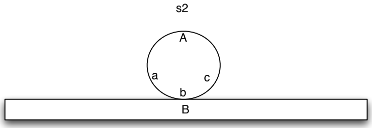
For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:



- The ball rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$

Rolling Action

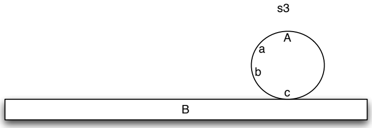
For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:



- The ball rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$

Rolling Action

For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:



- The ball rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$