Dynamic Interval Temporal Logic

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CS 112
Fall 2016
- 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 $\text{rolled}_m$.
   b. The ball $\text{crossed}_p$ the room.

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

S

NP  \text{figure}  VP

John    V

act

biked

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(5) S

NP: John

VP: figure

V: trans

departed

NP: Boston
Manner with Path Adjunction

(6)

S

NP  figure  VP

John  act  PP

biked  to the store

ground  trans
Path with Manner Adjunction

(7)

```
S
  |   
NP  VP
  |   
John V NP PP
      |   |
      |   |
      |  act
      | by car
      | NP
      |  ground
      |        
      | V NP
      |  trans
      |          
      | NP
      |  departed
      |       
      | NP
      |   
      | S
```
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
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.
(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 Inverse (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

\[ \text{DC}(A,B) \quad \text{EC}(A,B) \quad \text{PO}(A,B) \quad \text{TPP}(A,B) \quad \text{NTPP}(A,B) \]
Linguistic Approaches to Defining Paths

- Talmy (1985): Path as part of the Motion Event Frame
- 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.
(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

State (S)

Transition (T)

Process (P)

Derived Transition

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**: $\phi$ propositions. Evaluated in a state, $s$.
- **Programs**: $\alpha$, functions from states to states, $s \times s$.
  Evaluated over a pair of states, $(s, s')$.
- **Temporal Operators**: $\circ\phi$, $\diamond\phi$, $\square\phi$, $\phi U \psi$.
- **Program composition**:
  1. They can be ordered, $\alpha; \beta$ ($\alpha$ is followed by $\beta$);
  2. They can be iterated, $a^*$ (apply $a$ zero or more times);
  3. They can be disjoined, $\alpha \cup \beta$ (apply either $\alpha$ or $\beta$);
  4. They can be turned into formulas
     - $[\alpha]\phi$ (after every execution of $\alpha$, $\phi$ is true);
     - $\langle\alpha\rangle\phi$ (there is an execution of $\alpha$, such that $\phi$ is true);
  5. Formulas can become programs, $\phi?$ (test to see if $\phi$ 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.
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) \( (e_1, \alpha, e_2) \in \rightarrow \)

Labeled Transition System (LTS)

An action, \( \alpha \) 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. \(e_1 \xrightarrow{\alpha} e_3\)
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:

\[(13) \quad \phi_{e_1} \xrightarrow{\alpha} \neg \phi_{e_2}\]
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 $e_1@i$.

\begin{equation}
\begin{aligned}
\{\phi\}_e @i, \alpha, \{\neg\phi\}_e @i+1 \in \rightarrow (i, i+1),
\end{aligned}
\end{equation}

we use:

\begin{equation}
\begin{aligned}
\phi^i_{e_1} \xrightarrow{\alpha} \neg\phi^{i+1}_{e_2}
\end{aligned}
\end{equation}
Basic Transition Structure (Pustejovsky and Moszkowicz, 2011)

(15)

\[
\begin{array}{c}
\phi \\
\downarrow \\
e_i \\
\downarrow \alpha \\
e_{[i,i+1]} \\
\downarrow \\
e_{i+1} \\
\downarrow \\
\neg \phi
\end{array}
\]
\begin{equation}
(16) \quad x := y \text{ (ν-transition)} \\
\quad \text{“}x\text{ assumes the value given to } y\text{ in the next state.”} \\
\quad \langle M, (i, i + 1), (u, u[x/u(y)]) \rangle \models x := y \\
\quad \text{iff } \langle M, i, u \rangle \models s_1 \land \langle M, i + 1, u[x/u(y)] \rangle \models x = y
\end{equation}

\begin{equation}
(17) \\
\quad e^i[\cdot, i+1] \\
\quad x := y \quad e^i_1 \\
\quad e^i_{+1} \\
\quad e^i_{1} \\
\quad e^{i+1} \\
\quad A(z) = x \quad A(z) = y
\end{equation}
With a $\nu$-transition defined, a process can be viewed as simply an iteration of basic variable assignments and re-assignments:

$\begin{align*}
(e_1 \xrightarrow{\nu} e_2 \cdots \xrightarrow{\nu} e_n)
\end{align*}$
Directed Motion

(19) \( \text{loc}(z) = x_{e_1} \xrightarrow{\nu} \text{loc}(z) = y_{e_2} \)

When this test references the ordinal values on a scale, \( C \), this becomes a directed \( \nu \)-transition \( (\vec{\nu}) \), e.g., \( x \preceq y \), \( x \succeq y \).

(20) \( \vec{\nu} =_{df} e_i \xrightarrow{\nu} e_{i+1} \)
Directed Motion

(21)

\[ e_{i}^{[i,i+1]} \]

\[ x \leq y? \]

\[ e'_{1} \quad x := y \quad e_{2}^{i+1} \]

\[ \mathcal{A}(z) = x \quad \mathcal{A}(z) = y \]
Accomplishment Event Structure (Paths)

\[(22)\]

\[\begin{array}{c}
\alpha \\
\alpha \\
\ldots \\
\alpha \\
\end{array}\]

\[\begin{array}{c}
e_1 \\
e_2 \\
\phi \\
\phi \\
\end{array}\]

\[\begin{array}{c}
e_1 \alpha e_0 \rightarrow e_1 \\
e_2 \alpha e_1 \rightarrow e_2 \\
\ldots \\
e_k \alpha e_{k-1} \rightarrow e_k \\
\end{array}\]

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(23) **Motion leaving a trail:**

a. Assign a value, $y$, to the location of the moving object, $x$.
   \[ \text{loc}(x) := y \]

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);
quantifying the resulting trail

\[ \begin{align*}
 & \mathbf{p} = (b, l_2, l_3) \\
 & \mathbf{p} = (b, l_2) \\
 & \mathbf{p} = (b)
\end{align*} \]

p=(b,l_2,l_3)
p=(b,l_2)
p=(b)
l_1@t_1   l_2@t_2    l_3@t_3

Figure: Directed Motion leaving a Trail

(24) a. The ball rolled 20 feet.
\[ \exists \mathbf{p} \exists x \left[ \left( \text{roll}(x, \mathbf{p}) \land \text{ball}(x) \land \text{length}(\mathbf{p}) = [20, \text{foot}] \right) \right] \]
b. John biked for 5 miles.
\[ \exists \mathbf{p} \left[ \left( \text{bike}(j, \mathbf{p}) \land \text{length}(\mathbf{p}) = [5, \text{mile}] \right) \right] \]
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.
- \( \lambda \vec{z}\lambda y\lambda x[\text{build}(x, \vec{z}, y)] \)

- An ordinal scale drives the incremental creation forward
- A nominal scale acts as a test for completion (telicity)
- Mary is building a table.
- Change is measured over an **ordinal scale**.
- Trail, \( \tau \) is null.
Mary is building a table.

Change is measured over an **ordinal scale**.

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

Change is measured over an **ordinal scale**.

Trail, $\tau = [A, B, C]$
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, $\tau = [A, B, C, D, E]$; $table(\tau)$.
(25) a. John built a table.
    b. Mary walked to the store.

<table>
<thead>
<tr>
<th>$\text{build}(x, z, y)$</th>
<th>$\text{build}(x, z, y)^+$</th>
<th>$\text{build}(x, z, y), y = v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\neg\text{table}(v)$</td>
<td>$\text{table}(v)$</td>
<td></td>
</tr>
</tbody>
</table>

**Table:** Accomplishment: parallel tracks of changes
Dynamic Event Structure

(26)

\[
\begin{array}{c}
\text{e} \\
\alpha \\
\text{e}_1 \\
\phi? \\
\neg\phi? \\
\text{e}_{11} \rightarrow \text{e}_{12} \rightarrow \ldots \rightarrow \text{e}_{1k} \\
\end{array}
\]
Parallel Scales define an Accomplishment

\[ (27) \]

\[
\text{e} \\
\text{e}_1 \xrightarrow{\text{build}} \text{e}_2 \\
\text{e}_{11} \xrightarrow{\text{build}} \text{e}_{12} \ldots \xrightarrow{\text{build}} \text{e}_{1_k} \\
\quad \xrightarrow{\text{table?}} \\
\quad \xrightarrow{\text{table}(v)}
\]
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) \[ \text{loc}(z) = x \quad e_0 \xrightarrow{\vec{v}} \quad \text{loc}(z) = y_1 \quad e_1 \xrightarrow{\vec{v}} \quad \text{loc}(z) = y_2 \quad e_2 \]
The box slides across the floor.

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

$\left[ \text{slide} \right] = 
\langle \lbrack \partial A \cap \partial B = 1 \rbrack \circ s_1, \lbrack \partial A \cap \partial B = 1 \rbrack \circ s_2, \lbrack \partial A \cap \partial B = 1 \rbrack \circ s_3 \rangle$;
- The box slides across the floor.
- $[\text{slide}] = \langle [\partial A \cap \partial B = 1] @ s_1, [\partial A \cap \partial B = 1] @ s_2, [\partial A \cap \partial B = 1] @ s_3 \rangle$;
The box hops across the floor.

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

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

\[ \langle [\partial A \cap \partial B = 1] @ s_1, [\partial A \cap \partial B = 0] @ s_2, [\partial A \cap \partial B = 1] @ s_3 \rangle; \]
For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:

\[ \langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle \]

- The ball rolls across the floor.
Rolling Action

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

- The ball rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$
For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:

The ball rolls across the floor.

$\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$