Spatial Relations in Motion Predicates

- **Topological Path Expressions**
  - arrive, leave, exit, land, take off

- **Orientation Path Expressions**

- **Topo-metric Path Expressions**

- **Topo-metric Orientation Expressions**
  - just below, just above
Spatial Relations in Motion Predicates

- **Topological Path Expressions**
  - arrive, leave, exit, land, take off

- **Orientation Path Expressions**
  - climb, descend
Spatial Relations in Motion Predicates

- **Topological Path Expressions**
  - arrive, leave, exit, land, take off
- **Orientation Path Expressions**
  - climb, descend
- **Topo-metric Path Expressions**
  - approach, near, distance oneself
Spatial Relations in Motion Predicates

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  arrive, leave, exit, land, take off
- **Orientation Path Expressions**
  climb, descend
- **Topo-metric Path Expressions**
  approach, near, distance oneself
- **Topo-metric orientation Expressions**
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• Manner construction languages
  Path information is encoded in directional PPs and other adjuncts, while verb encode manner of motion
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English, German, Russian, Swedish, Chinese

Path construction languages
Language Data

- **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
(57) a. The *event* or situation involved in the change of location;
(58) 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);
Defining Motion (Talmy 1985)

(59) 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;
(60) 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);
Defining Motion (Talmy 1985)

(61) 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;
(62) 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

(63) 

S
  c
NP  VP
    c
John  V
      c
act  biked
Path Predicates

(64)

\[
S \quad \rightarrow \quad \text{NP} \quad \text{figure} \quad \text{VP} \\
\quad \downarrow \quad \quad \downarrow \quad \quad \downarrow \\
\quad \text{John} \quad \text{V} \quad \text{ground} \quad \text{NP} \\
\quad \quad \quad \downarrow \quad \quad \quad \downarrow \\
\quad \quad \text{departed} \quad \text{trans} \quad \text{Boston}
\]
Manner with Path Adjunction

(65) S
   /\   \ 
  /   \   
NP  VP
   /\   /\ 
  /   /   
John V PP
     /\   /
    /   /  
   biked to the store
      /\   /
     /   /
    act trans
Path with Manner Adjunction

(66)

```
S
  NP  VP
    John  V
        `ground`
        `trans`
        departed
        `by car` Boston
        `act`
PP
```
(67) a. Isabel climbed for 15 minutes.
(69) a. Isabel climbed for 15 minutes.
b. Nicholas fell 100 meters.
(71) a. Isabel climbed for 15 minutes.
   b. Nicholas fell 100 meters.

(72) a. There is an action (e) bringing about an iterated non-distinguished change of location;
(73) a. Isabel climbed for 15 minutes.
b. Nicholas fell 100 meters.

(74) a. There is an action (e) bringing about an iterated non-distinguished change of location;
b. The figure undergoes this non-distinguished change of location;
(75) a. Isabel climbed for 15 minutes.
   b. Nicholas fell 100 meters.

(76) a. There is an action (e) bringing about an iterated
    non-distinguished change of location;
   b. The figure undergoes this non-distinguished change of
      location;
   c. The figure creates (leaves) a path by virtue of the motion.
(77) a. Isabel climbed for 15 minutes.
    b. Nicholas fell 100 meters.

(78) a. There is an action (e) bringing about an iterated non-distinguished change of location;
    b. The figure undergoes this non-distinguished change of location;
    c. The figure creates (leaves) a path by virtue of the motion.
    d. The action (e) is performed in a certain manner.
(79) a. Isabel climbed for 15 minutes.
    b. Nicholas fell 100 meters.

(80) a. There is an action (e) bringing about an iterated non-distinguished change of location;
    b. The figure undergoes this non-distinguished change of location;
    c. The figure creates (leaves) a path by virtue of the motion.
    d. The action (e) is performed in a certain manner.
    e. The path is oriented in an identified or distinguished way.
Unlike pure manner verbs, this class of predicates admits of two compositional constructions with adjuncts.
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(83) **Manner of motion verb with path adjunct;**
    John climbed to the summit.
Unlike pure manner verbs, this class of predicates admits of two compositional constructions with adjuncts.

(85) **Manner of motion verb with path adjunct;**
    John climbed to the summit.

(86) **Manner of motion verb with path argument;**
    John climbed the mountain.
John act climbed to the summit

(87)
(88)

```
S
  NP  VP
  │  │
  John  V
  │  │
  figure  path
  │  │
  climbed  the mountain
```
Tracking Motion with RCC8: example of enter

\[
\begin{align*}
\text{t}_1 & \quad \text{A} \quad \text{B} \quad \text{DC(A,B)} \\
\text{t}_2 & \quad \text{A} \quad \text{B} \quad \text{EC(A,B)} \\
\text{t}_3 & \quad \text{A} \quad \text{B} \quad \text{PO(A,B)} \\
\text{t}_4 & \quad \text{A} \quad \text{B} \quad \text{TPP(A,B)} \\
\text{t}_5 & \quad \text{A} \quad \text{B} \quad \text{NTPP(A,B)}
\end{align*}
\]
Dynamic Interval Temporal Logic
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- **Path** verbs designate a distinguished value in the change of location, from one state to another.
Dynamic Interval Temporal Logic

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- **Manner of motion** verbs iterate a change in location from state to state.
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.
Directed Motion

\[(89) \quad \text{loc}(z) = x_{e_1} \xrightarrow{\nu} \text{loc}(z) = y_{e_2} \]

When this test references the ordinal values on a scale, this becomes a directed \( \nu \)-transition (\( \nu \rightarrow \)), e.g., \( x \xrightarrow{\nu} y \), \( x \xrightarrow{\nu} y \).
(91) $\text{loc}(z) = x_{e_1} \xrightarrow{\nu} \text{loc}(z) = y_{e_2}$

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

\[ x \neq y? \]

\[ x_e \rightarrow y_e \]
Directed Motion

(93) \[ \text{loc}(z) = x_{\text{e}_1} \rightarrow^\nu \text{loc}(z) = y_{\text{e}_2} \]

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

(94) \[ \tilde{\nu} =_{df} e_i \rightarrow^\nu e_{i+1} \]
Directed Motion

(95)

\[ e^{[i,i+1]} \quad \text{s.t.} \quad x \leq y \]

\[ e_i \quad x := y \quad e_{i+1} \]

\[ A(z) = x \quad A(z) = y \]
Manner-of-motion verbs introduce an assignment of a location value:

\[ \text{loc}(x) := y ; y := z \]
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\[ \text{loc}(x) := y; y := z \]

Directed motion introduces a dimension that is measured against:
\[ d(b, y) < d(b, z) \]
Manner-of-motion verbs introduce an assignment of a location value:
\[ \text{loc}(x) := y; y := z \]

Directed motion introduces a dimension that is measured against:
\[ d(b, y) < d(b, z) \]

Path verbs introduce a pair of tests:
\[ \neg \phi? \ldots \phi? \]
The execution of a change in the value to an attribute $A$ for an object $x$ leaves a trail, $\tau$. For motion, this trail is the created object of the path $p$ which the mover travels on; for creation predicates, this trail is the created object brought about by order-preserving transformations as executed in the directed process above.
The execution of a change in the value to an attribute $A$ for an object $x$ leaves a trail, $\tau$. 
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For motion, this trail is the created object of the path $p$ which the mover travels on;
The execution of a change in the value to an attribute $A$ for an object $x$ leaves a trail, $\tau$.

For motion, this trail is the created object of the path $p$ which the mover travels on;

For creation predicates, this trail is the created object brought about by order-preserving transformations as executed in the directed process above.
Motion Leaving a Trail

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

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

\[ \text{loc}(x) := y \]
(97) **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);

\[ b := y \]
(98) **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 $b$;
\[
p := (b)
\]
(99) **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 $y \neq z$

\[
y := z, y \neq z
\]
(100) **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 $p$;
Motion Leaving a Trail

(101) **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 \( p \);
   \[ p := (p, z) \]

f. Kleene iterate steps (d) and (e).
Quantifying the Resulting Trail

Figure: Directed Motion leaving a Trail
(103) a. The ball rolled 20 feet.
\[ \exists p \exists x \left[ \left( \text{roll}(x, p) \land \text{ball}(x) \land \text{length}(p) = [20, \text{foot}] \right) \right] \]
Quantifying the Resulting Trail

Figure: Directed Motion leaving a Trail

(104) a. The ball rolled 20 feet.
   \[ \exists p \exists x [\text{roll}(x, p) \land \text{ball}(x) \land \text{length}(p) = [20, \text{foot}]] \]

b. John biked for 5 miles.
   \[ \exists p [\text{bike}(j, p) \land \text{length}(p) = [5, \text{mile}]] \]
Generalizing the Path Metaphor

- We generalize the Path Metaphor to the analysis of the creation predicates.
Generalizing the Path Metaphor

- We generalize the Path Metaphor to the analysis of the creation predicates.
- We analyze creation predicates as predicates referencing two types of scales.
(105) a. John wrote a letter.
Type of Creation Verbs

(107) a. John wrote a letter.
b. Sophie wrote for hours.
Type of Creation Verbs

(109) a. John wrote a letter.
    b. Sophie wrote for hours.
    c. Sophie wrote for an hour.

(110) a. John built a wooden bookcase.
    b. *John built for weeks.
Some verbs expressing change are associated with a scale while others are not (scalar vs. non-scalar change).
Linguistic View on Scales

- Some verbs expressing change are associated with a scale while others are not (scalar vs. non-scalar change).
- There is a single scale domain (ordinal scale), which varies with respect to mereological complexity (two-point vs. multi-point) and specificity of the end point (bounded vs. unbounded).
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- Scales are classified on the basis of the attribute being measured:
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- PROPERTY SCALES: often found with change of state verbs.
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Scales are classified on the basis of the attribute being measured:
- PROPERTY SCALES: often found with change of state verbs.
- PATH SCALES: most often found with directed motion verbs.
Some verbs expressing change are associated with a scale while others are not (scalar vs. non-scalar change).

There is a single scale domain (ordinal scale), which varies with respect to mereological complexity (two-point vs. multi-point) and specificity of the end point (bounded vs. unbounded).

Scales are classified on the basis of the attribute being measured:

- PROPERTY SCALES: often found with change of state verbs.
- PATH SCALES: most often found with directed motion verbs.
- EXTENT SCALES: most often found with incremental theme verbs.
Various scholars have observed that for certain scalar expressions the scale appears not to be supplied by the verb.
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Various scholars have observed that for certain scalar expressions the scale appears not to be supplied by the verb.

For example, Rappaport Hovav 2008, Kennedy 2009 claim that “the scale which occurs with incremental theme verbs (extent scale) is not directly encoded in the verb, but rather provided by the referent of the direct object”.

This has lead them to the assumption that when nominal reference plays a role in measuring the change, V is not associated with a scale (denoting a non-scalar change).
Identify the source(s) of the measure of change.
Challenge for Scalar Models

- Identify the source(s) of the measure of change.
- What is the basic classification of the predicate with respect to its scalar structure?
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- What is the exact contribution of each member of the linguistic expression to the measurement of the change?
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- What is the basic classification of the predicate with respect to its scalar structure?
- What is the exact contribution of each member of the linguistic expression to the measurement of the change?
- What is the role of nominal reference in aspectual composition?
Verbs reference a specific scale.
• Verbs reference a specific scale.
• We measure change according to this scale domain.
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Scales are introduced by predication (encoded in a verb).
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Scales are introduced by predication (encoded in a verb).

Scales can be introduced by composition (function application).
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We measure change according to this scale domain.
Scales are introduced by predication (encoded in a verb).
Scales can be introduced by composition (function application).
Verbs may reference multiple scales.

Nominal scales: composed of sets of categories in which objects are classified;

Ordinal scales: indicate the order of the data according to some criterion (a partial ordering over a defined domain). They tell nothing about the distance between units of the scale.

Interval scales: have equal distances between scale units and permit statements to be made about those units as compared to other units; there is no zero. Interval scales permit a statement of "more than" or "less than" but not of "how many times more."

Ratio scales: have equal distances between scale units as well as a zero value. Most measures encountered in daily discourse are based on a ratio scale.
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Use multiple scalar domains and the “change as program” metaphor proposed in Dynamic Interval Temporal Logic (DITL, Pustejovsky 2011, Pustejovsky & Moszkowicz 2011).
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Define change as a transformation of state (cf. Galton, 2000, Naumann 2001) involving two possible kinds of result, depending on the change program which is executed:
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Define change as a transformation of state (cf. Galton, 2000, Naumann 2001) involving two possible kinds of result, depending on the change program which is executed:

- If the program is “change by testing”, Result refers to the current value of the attribute after an event (e.g., the house in build a house, the apple in eat an apple, etc.).
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Define change as a transformation of state (cf. Galton, 2000, Naumann 2001) involving two possible kinds of result, depending on the change program which is executed:

- If the program is “change by testing”, Result refers to the current value of the attribute after an event (e.g., the house in build a house, the apple in eat an apple, etc.).
- If the program is “change by assignment”, Result refers to the record or trail of the change (e.g., the path of a walking, the stuff written in writing, etc.).
Scale shifting
Pustejovsky and Jezek 2012

Scale Shifting is mapping from one scalar domain to another scalar domain.

ordinal $\Rightarrow$ nominal

nominal $\Rightarrow$ ordinal

ordinal $\Rightarrow$ interval

Scale Shifting may be triggered by:

- Adjuncts: for / slash left / in adverbials, degree modifiers, resultative phrases, etc.
- Arguments (selected vs. non-selected, semantic typing, quantification).
Scale Shifting is mapping from one scalar domain to another scalar domain.

*ordinal* ⇒ *nominal*

*nominal* ⇒ *ordinal*

*ordinal* ⇒ *interval*

...
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- ordinal $\Rightarrow$ nominal
- nominal $\Rightarrow$ ordinal
- ordinal $\Rightarrow$ interval

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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. 

\[ \text{build}(x, z, y) \]

An ordinal scale drives the incremental creation forward.

A nominal scale acts as a test for completion (telicity).

Pustejovsky - Brandeis

Computational Event Models
Accomplishments are Lexically Encoded Tests.
Accomplishments are Lexically Encoded Tests.
John built a house.
Accomplishments are Lexically Encoded Tests. John built a house.

- Test-predicates for creation verbs
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- build selects for a quantized individual as argument.
- $\lambda \tilde{z} \lambda y \lambda x[\text{build}(x, \tilde{z}, y)]$
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  \[\lambda\tilde{z}\lambda y\lambda x[\text{build}(x, \tilde{z}, y)]\]
- 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, $\tau = [A, B, C, D, E]$; $table(\tau)$. 
Accomplishments

(111) a. John built a table.
    b. Mary walked to the store.

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

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

(112)

\[ e \]

\[ e_1 \quad \alpha \quad e_2 \]

\[ \neg \phi? \]

\[ e_{11} \quad \alpha \quad e_{12} \quad \ldots \quad \alpha \quad e_{1k} \]

\[ \phi \]

\[ \phi? \]
Parallel Scales define an Accomplishment

(113)

\[
\begin{aligned}
& e_1 \xrightarrow{\text{build}} e_2 \\
& e_1 \xrightarrow{\neg \text{table}} e_1, e_{12}, \ldots, e_{1k} \xrightarrow{\text{build}} \text{table}(v)
\end{aligned}
\]
Motivation

- We need to move beyond shallow semantic parsing to deeper semantic analysis of text;
- Understanding sentences requires more than identifying events and participants and giving them semantic role labels;
- It is essential to recognize temporal sequencing within the event and any changes in state that might have occurred.
A hierarchical, domain-independent verb lexicon that groups verbs into classes based on similarities in their syntactic and semantic behavior (Schuler, 2005);

Each class in VerbNet defines:

- a set of member verbs;
- semantic roles for the predicate-argument structure of these verbs;
- selectional restrictions on the arguments; and
- frames consisting of a syntactic description and a corresponding semantic representation.
Used extensively in:

- Linking lexical resources to ontologies (Brown et al. (2017));
- Semantic role labeling tasks (Shi and Mihalcea, 2005);
- Word sense disambiguation for verbs (Abend et al., 2008; Brown et al., 2014; Kawahara and Palmer, 2014);
- Inference-enabling tasks (Giuglea and Moschitti, 2006; Loper et al., 2007).

But ...
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- Linking lexical resources to ontologies (Brown et al. (2017));
- Semantic role labeling tasks (Shi and Mihalcea, 2005);
- Word sense disambiguation for verbs (Abend et al., 2008; Brown et al., 2014; Kawahara and Palmer, 2014);
- Inference-enabling tasks (Giuglea and Moschitti, 2006; Loper et al., 2007).

But ... Semantic representations can be improved for consistency and greater expressiveness, e.g., linking semantic roles to predicative changes within the verb’s subevents (Zaenen et al., 2008), typing over frames (Danlos et al. 2016);

- Generative Lexicon has long focused on articulating the semantics of event structure in language; more recent work identifies dynamic change associated with subevents (Pustejovsky, 1995, 2013).
### VerbNet Classes - Run-51.3.2

<table>
<thead>
<tr>
<th>Members</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AMBLE</td>
<td>(FN 1; WN 1; G 1)</td>
</tr>
<tr>
<td>AMBULATE</td>
<td>(WN 1; G 1)</td>
</tr>
<tr>
<td>BACKPACK</td>
<td>(WN 1)</td>
</tr>
<tr>
<td>BOLT</td>
<td>(FN 1, 2, 3, 4; WN 4; G 1)</td>
</tr>
<tr>
<td>BOUND</td>
<td>(FN 1; WN 1; G 1)</td>
</tr>
<tr>
<td>BREEZE</td>
<td></td>
</tr>
<tr>
<td>BUSTLE</td>
<td>(WN 1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Roles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent</td>
<td>[+animate]</td>
</tr>
<tr>
<td>Theme</td>
<td>[+animate</td>
</tr>
<tr>
<td>Location</td>
<td>[+concrete]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frames</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NP V</td>
<td></td>
</tr>
<tr>
<td><strong>Example</strong></td>
<td>&quot;The horse jumped.&quot;</td>
</tr>
<tr>
<td><strong>Syntax</strong></td>
<td>THEME V</td>
</tr>
<tr>
<td><strong>Semantics</strong></td>
<td>MOTION(DURING(E), THEME)</td>
</tr>
<tr>
<td>NP V PP_LOCATION</td>
<td></td>
</tr>
<tr>
<td><strong>Example</strong></td>
<td>&quot;The horse jumped over the fence.&quot;</td>
</tr>
<tr>
<td><strong>Syntax</strong></td>
<td>THEME V {{+spatial}} LOCATION</td>
</tr>
<tr>
<td><strong>Semantics</strong></td>
<td>MOTION(DURING(E), THEME) PREP(E, THEME, LOCATION)</td>
</tr>
</tbody>
</table>
Each VerbNet class contains semantic representations compatible with the members and syntactic frames of class; Representation makes use of semantic predicates:

- motion
- perceive
- cause

References semantic role participants and an event variable $E$.

Some of these are meant to describe the participants during various stages of the event evoked by the syntactic frame.
(114) *The horse ran into the barn.*

NP V PP
Theme V Destination

motion\(\text{during}(E, \text{Theme})\)

path\_rel\(\text{start}(E, \text{Theme, Initial\_location, ch\_of\_loc, prep})\)

path\_rel\(\text{during}(E, \text{Theme, Trajectory, ch\_of\_loc, prep})\)

path\_rel\(\text{end}(E, \text{Theme, Destination, ch\_of\_loc, prep})\)
The arguments of each predicate are represented using the semantic roles for the class;

Participants mentioned in the syntax as well as those not expressed are accounted for in the semantics;

The second component of the first path_rel semantic predicate above includes an unidentified Initial_location;

Temporal sequencing is indicated with the second-order predicates start, during, and end;
John herded the sheep into the barn.

NP V NP PP

cause(Agent, E)

Agent V Theme Destination

motion(during(E), Theme)

path_rel(start(E), Theme, Initial_location, ch_of_loc, prep)

path_rel(during(E), Theme, Trajectory, ch_of_loc, prep)

path_rel(end(E), Theme, Destination, ch_of_loc, prep)
Semantic representations capture generalizations about the semantic behavior of the class member as a group;

For some classes (e.g., Battle-36.4), verbs are semantically coherent, *battle, skirmish, war*;

(116) *Sparta warred with Athens.*

NP V PP
Agent V {with} Co-Agent
social_interaction(during(E), Agent, Co-Agent)
conflict(during(E), Agent, Co-Agent)
possible_contact(during(E), Agent, Co-Agent)
manner(Hostile, Agent, Co-Agent)
Other classes (e.g., Other Change of State-45.4) contain widely diverse member verbs, *dry, gentrify, renew, whiten*;

Semantics for this class ignores specific type of state change in order to be general enough for any verb in the class when used in a basic transitive sentence;

(117)  \textit{John dried the clothes.}

\begin{align*}
\text{NP} & \text{ V} \text{ NP} \\
\text{Agent} & \text{ V} \text{ Patient} \\
\text{path\_rel}(\text{start}(E), \text{Initial state}, \text{Patient}, \text{ch\_of\_state}, \text{prep}) \\
\text{path\_rel}(\text{result}(E), \text{Result}, \text{Patient}, \text{ch\_of\_state}, \text{prep}) \\
\text{cause}(\text{Agent}, \text{E})
\end{align*}
VerbNet has expanded its coverage (Kipper et al., 2008);

Class and verb components have improved in clarity and consistency (Bonial et al., 2011; Hwang, 2014);

Zaenen et al. (2008) show VerbNet is unable to support some temporal and spatial inferencing tasks;

- From *The diplomat left Bhagdad* you can’t infer *The diplomat was in Bhagdad*;
- For several motion classes, End(E) was given but not Start(E);
- Some classes involving change of location of participants (e.g., gather, mix) did not include a motion predicate at all.
Efforts to use VerbNet in human-computer interaction found that an enriched event representation would facilitate the interaction between the language parsing and the planning components of the system (Narayan-Chen et al., 2017);

Attempts to use VerbNet in robotics show the need for:
- a first-order representation;
- more specific event causal relation, instead of \texttt{cause}(Agent,E);
- more explicit temporal relations, over reified events rather than functional expressions over the matrix event, E.
(118) \textit{Mary threw the ball.}

NP V NP
Agent V Theme
\texttt{exert\_force}(during(\textit{E}_0), Agent, Theme)
\texttt{contact}(end(\textit{E}_0), Agent, Theme)
\neg \texttt{contact}(during(\textit{E}_1), Agent, Theme)
\texttt{motion}(during(\textit{E}_1), Theme)
\texttt{cause}(Agent, \textit{E}_1)
(119) a. **State:** a simple event, evaluated without referring to other events: *be sick, love, know*

\[ S \downarrow e \]

b. **Process:** a sequence of events identifying the same semantic expression: *run, push, drag*

\[ P \quad e_1 \ldots e_n \]

c. **Transition:** an event identifying a semantic expression evaluated with respect to its opposition: *give, open; build:*

Binary transition (achievement): \( \neg \phi \in S_1 \), and \( \phi \in S_2 \)

\[ T \quad S_1 \quad S_2 \]

Complex transition (accomplishment): \( \neg \phi \in P \), and \( \phi \in S \)

\[ T \quad P \quad S \]
First-Order Subevent Representations

(120) a. The destroyer is sinking a boat.
   \[ \exists e_1 \exists y [ \text{sink\_act}(e_1, \iota x (\text{destroyer}(x), y) \land \text{boat}(y)) ] \]

b. The destroyer sank a boat.
   \[ \exists e_1, e_2 \exists y [ \text{sink\_act}(e_1, \iota x (\text{destroyer}(x), y) \land \text{boat}(y) \land \text{sink\_result}(e_2, y) \land e_1 < e_2] \]

c. A boat sank.
   \[ \exists e_2, e_1 \exists x, y [ \text{sink\_result}(e_2, y) \land \text{boat}(y) \land \text{sink\_act}(e_1, x, y) \land e_1 < e_2] \]
Event structure is integrated with first-order dynamic logic;

- Represents the attribute modified in the course of the event (the location of the moving entity, the extent of a created or destroyed entity, etc.);

- A complex event can be modeled as a sequence of frames;

- To adequately model events, the representation should track the change in the assignment of values to attributes in the course of the event.

- This includes making explicit any predicative opposition denoted by the verb:
  - *die* encodes going from $\neg\text{dead}(e_1, x)$ to $\text{dead}(e_2, x)$;
  - *arrive* encodes going from $\neg\text{loc\_at}(e_1, x, y)$ to $\text{loc\_at}(e_2, x, y)$. 
Dynamic Event Structure

Pustejovsky and Moszkowicz (2011)

Two Primitive Event Types

State

\[ e^i \]

\[ \varphi \]

Simple Transition

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

\[ e^i \]

\[ e^1 \]

\[ e^2_{[i+1]} \]

\[ \alpha \]

\[ \varphi \]

\[ \neg \varphi \]

Derived Vendler Event Types

a. State

\[ e^i \]

\[ \varphi \]

b. Process

\[ e_{[i,j]} \]

\[ \varphi \]

c. Achievement

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

\[ e^i \]

\[ e^1 \]

\[ e^2_{[i+1]} \]

\[ \alpha \]

\[ \varphi \]

\[ \neg \varphi \]

d. Accomplishment

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

\[ e^i_{[i,j]} \]

\[ e^1 \]

\[ e^2_{[j+1]} \]

\[ \alpha \]

\[ \varphi \]

\[ \neg \varphi \]
Elimination of tripartite division of temporal span of the event, i.e., \textbf{Start}, \textbf{During}, \textbf{End};

Subevents introduced as first-order quantified individuals, $e_1, e_2, \ldots$;

Temporal (Allen-like) relations can be employed for verb-class specific semantics:

- \textbf{before$(e_2, e_3)$}
- \textbf{meets$(e_2, e_3)$}
- \textbf{while$(e_2, e_3)$}

Causation is an event-relation: \textbf{cause$(e_1, e_2)$}
Before/After VerbNet Event Semantics - *jump*

VerbNet 3.3

(121) *The lion tamer jumped the lion through the hoop.*

NP V NP PP
Agent V Theme Trajectory

*motion*(during(E), Theme)
*path_rel*(start(E), Theme, ?Initial_location, ch_of_loc, prep)
*path_rel*(during(E), Theme, Trajectory, ch_of_loc, prep)
*path_rel*(end(E), Theme, ?Destination, ch_of_loc, prep)
*cause*(Agent, E)

VN-GL

(122) *The lion tamer jumped the lion through the hoop.*

*has_location*(e₁, Theme, ?Initial_Location)
*do*(e₂, Agent)
*motion*(e₃, Theme, Trajectory)
*cause*(e₂, e₃)
*has_location*(e₄, Theme, ?Destination)
State predicate **has_location**, with event argument $e_1$; Theme argument for the object in motion; and an Initial_location argument;

- The motion predicate is underspecified as to the manner of motion in order to be applicable to all 97 verbs in the class;

- A final **has_location** predicate indicates the Destination of the Theme at the end of the event;

- Any uninstantiated roles in a frame are preceded by ?, such as Initial_location and Trajectory.
(123) The rabbit *hopped across the lawn.*

motion(during(E), Theme)

path_rel(start(E), Theme, ?Initial_location, ch_of_loc, prep)

path_rel(during(E), Theme, Trajectory, ch_of_loc, prep)

path_rel(end(E), Theme, ?Destination, ch_of_loc, prep)

(124) The rabbit *hopped across the lawn.*

has_location($e_1$, Theme, ?Initial_Location)

motion($e_2$, Theme, Trajectory)

has_location($e_3$, Theme, ?Destination)
Specifying causation: \texttt{cause}(e_1, e_2);

Adding underspecified action: \texttt{do}.

\begin{itemize}
\item \texttt{has\_location}(e_1, \text{Theme}, ?\text{Initial\_Location})
\item \texttt{do}(e_2, \text{Agent})
\item \texttt{motion}(e_3, \text{Theme}, ?\text{Trajectory})
\item \texttt{cause}(e_2, e_3)
\item \texttt{has\_location}(e_4, \text{Theme}, \text{Destination})
\end{itemize}

\begin{equation}
\text{(125) } \text{The farmer herded the sheep into the meadow.}
\end{equation}
Specifying subtypes of causation: \texttt{exert\_force} \subseteq \texttt{cause};

Adding new constraints: \texttt{contact}.

(126) \textit{John pushed the plate to the edge of the table.}

\texttt{has\_location}(e_1, \text{Theme}, \text{?Initial\_Location})

\texttt{cause}(e_2, e_3)

\texttt{contact}(e_2, \text{Agent, Theme})

\texttt{exert\_force}(e_2, \text{Agent, Theme})

\texttt{motion}(e_3, \text{Theme, ?Trajectory})

\texttt{has\_location}(e_4, \text{Theme, Destination})
Comparing to VerbNet 3.3

(127)  *John pushed the plate to the edge of the table.*

\[\begin{align*}
&\text{cause}(\text{Agent}, \ E) \\
&\text{contact}(\text{during}(\ E), \ \text{Agent}, \ \text{Theme}) \\
&\text{exert\_force}(\text{during}(\ E), \ \text{Agent}, \ \text{Theme}) \\
&\text{path\_rel}(\text{start}(\ E), \ \text{Theme}, \ ?\text{Initial}\_\text{location}, \ \text{ch\_of\_loc}, \ \text{prep}) \\
&\text{path\_rel}(\text{during}(\ E), \ \text{Theme}, \ \text{Trajectory}, \ \text{ch\_of\_loc}, \ \text{prep}) \\
&\text{path\_rel}(\text{end}(\ E), \ \text{Theme}, \ ?\text{Destination}, \ \text{ch\_of\_loc}, \ \text{prep}) \\
&\text{motion}(\text{during}(\ E), \ \text{Theme})
\end{align*}\]
(128)  *Elena guided Frank through the building.*

\[
\begin{align*}
\text{has\_location}(e_1, \text{Theme, } \text{?Initial\_Location}) \\
\text{has\_location}(e_2, \text{Agent, } \text{?Initial\_Location}) \\
\text{motion}(e_3, \text{Agent, Trajectory}) \\
\text{motion}(e_4, \text{Theme, Trajectory}) \\
\text{has\_location}(e_5, \text{Agent, } \text{?Destination}) \\
\text{has\_location}(e_6, \text{Theme, } \text{?Destination}) \\
\text{while}(e_3, e_4)
\end{align*}
\]
(129)  \textit{John died.}
\begin{align*}
\text{alive}(e_1, \text{Patient}) \\
\neg \text{alive}(e_2, \text{Patient})
\end{align*}

(130)  \textit{The balloon burst.}
\begin{align*}
\text{has}_\text{state}(e_1, \text{Patient}, \text{Initial}_\text{State}) \\
\text{opposition}(\text{Initial}_\text{State}, \text{V}_\text{Result}) \\
\text{has}_\text{state}(e_2, \text{Patient}, \text{V}_\text{Result})
\end{align*}
The clothes *dried wrinkled.*

NP  V  AP
Theme  V  Result
\text{has\_state}(e_1, \text{Patient, Initial\_State})
\text{has\_state}(e_2, \text{Patient, V\_Result})
\text{has\_state}(e_2, \text{Patient, Result})
\text{opposition}(\text{Initial\_State, V\_Result})
\text{opposition}(\text{Initial\_State, Result})
Members have verb-specific features, either increase (e.g., *rise*), decrease (e.g., *fall*) or fluctuate (e.g., *vary*).

Direction is a variable whose value can be found in context from the particular verb’s verb-specific feature.

(132) *The price of oil rose by 500% from $5 to $25.*

\[\text{has\_val}(e_1, \text{Patient}, \text{Initial\_State})\]

\[\text{change\_value}(e_2, \text{Direction}, \text{Extent}, \text{Attribute}, \text{Patient})\]

\[\text{has\_val}(e_3, \text{Patient}, \text{Result})\]
Results

- VerbNet is becoming one of the most important lexical resources in the community, providing syntactic behavior clustering, argument structure listing, semantic role labels, and linkages between these levels;
- The semantic representations for VerbNet classes are formally and expressively lacking in several respects, relating to the applicability of VerbNet resources to inferencing, HCI, human-robot communication, etc.;
- Generative Lexicon Event Structure can be easily integrated into the representation associated with verb classes, addressing these issues;
- Changes have been made automatically to 65 classes and manually checked for 41;
- Future work includes semantics for verbs of creation, transformation, perception, and experience.