Breaking the window hard: Forces and verbs in Frame Semantics
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1 The domain of force verbs
   --> A puzzle: interaction between force modifiability and force result
2 Theoretical tools
   --> Causation
3 Frame models: a suggestion (work in progress!)
4 Open Questions

1 The domain of force verbs (joint work with Joost Zwarts)
   - A force verb is any verb of which the root can occur in a sentence that describes a situation in which an object A (the force exerter) exerts a physical force (however light) on another object B (the force recipient) without necessarily implying a change in the properties of B, yet while allowing for that change.
   - force verbs in our sense: *schlagen* (to hit), *drücken* (to push), *ziehen* (to pull), *reiben* (to rub), *pressen* (to press), *treten* (to kick)
   - not force verbs in our sense: *brechen* (to break), *werfen* (to throw), *schleppen* (to drag) (because they entail a change), *stehen* (stand) (because it doesn’t allow change)
   - close relation with contact (force typically requires contact and contact typically involves some amount of force)

A puzzle: interaction between force modifiability and force result

   - The specification of a result (*ein* in (1a)) of the force seems to restrict the possibility of force modification
     (1) a. Thomas schlägt das Fenster (*hart*/*leicht) ein.  
         Thomas hits the window (*hard*/*lightly*) in
         Thomas breaks the window (*hard*/*lightly*).
     b. Thomas schlägt (hart/leicht) gegen das Fenster.
         Thomas hits (hard/lightly) against the window

   - Also confirmed in questionnaire study with more examples (see appendix):
     test sentences with force verbs with and without resultative particle/preposition and with force (*hard*/*lightly*) or speed (*quickly*/*slowly*) modifier (temporal/speed modifiers were used in order to determine whether all modification is out if a (force) result is specified, or just modification of the force component)

   - 158 participants rated sentences on a 4-point Likert scale:
     1 – clearly bad, 2 – maybe bad, 3 – maybe good, 4 – clearly good
- results:

<table>
<thead>
<tr>
<th></th>
<th>without result (schlagen)</th>
<th>with result (einschlagen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>force (leicht/hart)</td>
<td>80% / 65%</td>
<td>55% / 31%</td>
</tr>
<tr>
<td>speed (langsam/schnell)</td>
<td>52.5% / 55.5%</td>
<td>76% / 82%</td>
</tr>
</tbody>
</table>

Table 1: Percentages of ratings 3 (maybe good) and 4 (clearly good) for all test sentences

- sentences without a resultative particle or preposition and a force modifier were judged significantly better than sentences with a resultative particle or preposition and a force modifier (odds: 4.9, p = .02 for leicht; 8.1, p < .01 for hart)
- sentences with a resultative particle or preposition and a speed modifier were judged significantly better than sentences with a resultative particle or preposition and a force modifier (odds: 4.05, p = .03 for langsam vs leicht; 7, p < .01 for schnell vs leicht; and 15.7, p < .001 for langsam vs hart, 27.25, p < .001 for schnell vs hart)

2 Theoretical tools (joint work with Joost Zwarts)

- The internal properties of events are accessed through the paths they describe in real or conceptual space, e.g. Gärdenfors (2014).
- A path is constituted by a sequence of force vectors representing the force that the agent exerts on the patient at each point of time during the event (Wolff 2007).
- We assume a general notion of path which includes constant paths (e.g. Talmy 2000) (cf. Figures 1b+d).

![Diagram of paths]

Figure 1: Subsequent ‘snapshots’ \( p(t_0), p(t_1), p(t_2) \) from different paths

- Definition force vectors:
There is a full set of located force vectors that have an (i) origin, (ii) magnitude, and (iii) direction. This set includes zero vectors. Each set of force vectors with the same spatial origin constitutes a vector space, with the appropriate properties. We access space exclusively through located force vectors. A zero force vector is equivalent with an ‘old-fashioned’ point in space; a non-zero force vector \( f \) can be used
to represent a force with magnitude $|f|$ working at point origin($f$) = 0$.

- **Definition paths:**
  A path is a continuous function from a time interval $[t_0,t_1]$ to the set of located force vectors.
  Roughly speaking, a path is a sequence of positions at which forces might be exerted. 
  $p(t)$ is the force vector representing the force exerted at time $t$. 
  A path $p$ may be constant, i.e. map every $t$ of its domain to the same vector $f$ (cf. Figure 1b+d).
  A *force path* is a path that includes non-zero force vectors in its range (cf. Figure 1a+b).

- Additionally, the following needs to be defined:
  Some mereological structure, to allow sums (+) of events.
  For every event $e$, there is the interval $\text{TIME}(e)$ that represents the running time of $e$.
  For any event $e$, $\text{PATH}(e)$ is the path that corresponds to $e$, if defined.

- Resultative sentences involve a representation with two events for caused results (Parsons 1990, Pustejovský 1991).

**Causation**

- **CAUSE** is defined as follows (cf. Figure 2):

  $\text{CAUSE}(e_1,e_2):$ if $\text{PATH}(e_1)(t_i) + \text{TREND}(e_1)(t_i)$ is collinear with $\text{PATH}(e_2)$ while $\text{TREND}(e_1)(t_i)$ is not.

  - *In words:* $\text{CAUSE}(e_1,e_2)$ holds if the patient's force tendency $\text{TREND}(e_1)(t_i)$ does not point in the direction of the path of the second event $\text{PATH}(e_2)$, but the resultant of the agent's force $\text{PATH}(e_1)(t_i)$ does (capturing Talmy's insight that the agent's force "overcomes" the patient's force). (Goldschmidt & Zwarts, to appear)

![Figure 2: Force interaction in CAUSE(e_1,e_2) at moment t_i](image)

- the path assigned to the second event is a pure spatial path (e.g. the movement of glass shards); the dashed line in Figure 2 is not a vector, but a spatial path constituted by
zero vectors
- Why the ungrammaticality of (1a) and similar sentences?
  After the vector computation, the original force vectors of \textsc{Path}(e_1) become
  unavailable for modification by any adverb that requires a force vector with a
  magnitude bigger than zero (and the only other "attachment site" is \textsc{Path}(e_2), a spatial
  path with only zero force vectors).

3 Frame models: a suggestion
- based on Goldschmidt et. al. (to appear), but very much work in progress
- Frames as recursive attribute-value structures (Petersen, 2015)
- force and movement are components of force verbs, relation expressed by located force
  vectors that form a path (see above)
- \textsc{Force Vector} is an attribute of the force component, of which \textsc{Origin}, \textsc{Direction} and
  \textsc{Magnitude} are attributes in turn (these are the components/aspects of force vectors as
  in the definition above)
- \textsc{Path} is an attribute of the movement component, of which \textsc{Position} is an attribute in
  turn (being faithful to the above definition of 'path' as a sequence of positions)
- \textsc{Position} and \textsc{Origin} lead to the same node (the origin of a force vector marks a position
  on the path/trajectory of an object)\footnote{Participants of events are defined in Goldschmidt & Zwarts (to appear); please see Goldschmidt et. al. (to appear) for how to implement event participants into frames, including a link to the two components movement and force. I leave this out here for simplicity's sake.}

Figure 3: A first frame model for force verbs (without result - Thomas schlägt (hart/leicht) gegen das
Fenster.)
- each moment $t_i$ of the run time of the event is mapped to a new force vector; what is missing here is a function like e.g. that of Naumann (2013) to represent positions of objects throughout the run time of the event
- adverbs like *lightly* and *hard* modify the magnitude of the force vector(s)

- if a result of the force exertion is specified via a particle or preposition, **RESULT** will be added as an attribute of the force vector (of that moment $t_i$), with the particle/preposition as its value (the particle/preposition introduces the second event)

```
force verb

  force

  movement

force vector

force path

  path

non-zero

  origin

  position

magnitude
direction

result

ein
```

Figure 4: A first frame model for force verbs (with result - Thomas schlägt das Fenster (*hart*/leicht) ein.), force path is $\text{PATH}(e_i)(t_i)$ from Figure 2

- the particle or preposition introduces a second event (cf. Figure 5)
Figure 5: A first frame model for the particle/preposition, spatial path is $\text{PATH}_2(e_2)$ from Figure 2

4 Open Questions

- How to build in a function similar to that of Naumann (2013) to track the position of objects throughout the run time of the event?
- Related: In Goldschmidt et. al. the values of the force component and movement component are events; this is a bit more difficult here. A path (movement component) is associated to an event, but the force vectors (force component) build up that path during the run time of one event.
- How to incorporate the condition that allows results to be caused? (maybe something along the line of Osswald & Van Valin, this conference)

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Thank you!

References


**Appendix:** Some example sentences from the questionnaires

- Julia drückt hart gegen die Tür.
  ‘Julia pushes hard against the door.’
- Maike drückt die Pappe nach dem Kleben schnell an.
  ‘Maike presses the cardboard quickly together after gluing it.’
- Sandra drückt die Seite vom Karton langsam ein.
  ‘Sandra pushes the sides of the cardboard box towards each other.’
- Christ drückt die Tür hart zu.
  ‘Chris closes the door hard (while pushing it).’
- Tobias schlägt das Fenster leicht ein.
  ‘Tobias breaks the window lightly.’
- Alex schlägt schnell auf den Nagel.
  ‘Alex quickly hits the nail.’
- Alex schlägt den Nagel langsam in die Wand.
  ‘Alex hits the nail slowly into the wall.’
- Tobias zieht leicht an der Tür.
  ‘Tobias pulls lightly on the door.’
- Andrea zieht langsam an Florians Arm.
‘Andrea pulls slowly on Florian’s arm.’
- Maike zieht die Wurzeln hart aus der Erde.
  ‘Maike pulls the roots hard out of the earth.’
- Jan zieht die Tür leicht zu.
  ‘Jan closes the door lightly (while pulling it).’