Hitting the nail on the head: Force vectors in verb semantics

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Summary:

There is a growing recognition of the role of forces in verb meanings (e.g. Talmy, 2000; Wolff, 2007; Roßdeutscher & Pross, 2015). Forces are described as e.g. vectors to analyse causative verbs like *enable* and verbs like *pull*. Yet little attention is given to the observation that the specification of a force result prohibits modification of the force (cf. 1 vs 2).

  (1) Maria schlug auf den Nagel.   (2) Maria schlug den Nagel in die Wand.
      Maria hit   on the nail   Maria hit   the nail   in the wall
      'Maria hit the nail.'   'Maria hit the nail into the wall.'

Taking Neo-Davidsonian events as a starting point, we present an analysis of force verbs as referring to events that have paths with force-dynamic properties. Paths are treated as sequences of possibly zero force vectors, created by a moving or stationary agent. Force modifiers such as *hard* apply to the path of an event, if the path contains a point of forceful contact between agent and patient, represented as a non-zero force vector.

Events such as those in (2) are taken to be complex events, linked by a causal relation (Pustejovsky, 1991). The composition of this complex causal event makes the forces of the individual events (expressed in their paths) inaccessible for modification.

The treatment of a.o. combinations with prepositions (e.g. *ziehen an* (pull on) vs. *drücken auf* (push on)), the entailment of (1) by (2) above or the relation between the PP in (1) and direct object in (2) all follow naturally from our analysis.

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1 Force dynamics and force verbs

There is a growing attention for the role of forces in the semantic analysis of verbs, in cognitive semantics (e.g. Talmy, 2000; Croft, 2012; Gärdenfors, 2014), but also, more recently, in formal semantics (Van Lambalgen & Hamm, 2008; Copley & Harley, 2015; Rossdeutscher & Pross, 2015). One approach to force dynamics models forces as *vectors* located in space (e.g Wolff 2007), giving a detailed analysis of the use of causal verbs like *enable* or *prevent* in motion situations, but without fitting those force vectors into a compositional semantics. Copley & Harley (2015), on the other hand, offer a general compositional framework in which the event argument of any dynamic verb is reanalyzed as a force, defined more abstractly as a *function* from situations to situations. Obviously, there is a gap between a concrete, lexical-semantic notion of force vectors and an abstract, compositional notion of force functions.

We contribute towards bridging this gap by addressing a set of questions raised by *force verbs* in German, like *schlagen* 'hit', *berühren* 'touch', *reiben* 'rub', *streicheln* 'stroke', *drücken* 'push', *ziehen* 'pull'. These verbs can be used to describe the exertion of a force on an object, without implying any change in the position or state of that object (1), although they can also have a resultative use (2). Other languages have similar verbs with similar properties, like the "impact verbs" in English (Jackendoff, 1990; Levin, 1993).

(1) Maria schlug auf den Nagel.   (2) Maria schlug den Nagel in die Wand.
      Maria hit   on the nail   Maria hit   the nail   in the wall
      'Maria hit the nail.'   'Maria hit the nail into the wall.'

➢ The effect of the hitting force in (1) is not expressed, while it causes the nail to move in (2). How can we account for the relation between the two uses of *schlagen* in (1) and (2) (i.e. that (2) entails, but is not entailed by (1))?

➢ The PP *auf den Nagel* in (1) modifies the location of the force and the PP *in die Wand* in (2) the movement of the nail? How can these different roles of PPs be accounted for?

➢ How does the force exertion in force verbs relate to aspectual distinctions (punctual *schlagen* vs continuous *drücken*), different directions ('internal' *drücken* vs 'external' *ziehen*), and intensities ('intensive' *schlagen* vs 'non-intensive' *berühren*)?

➢ How can such lexical distinctions have compositional implications? Verbs may require a specific preposition depending on the force direction (cf. *an etwas ziehen* 'pull (on) something' vs *auf etwas drücken* 'push (at) something') or (dis)allow modification by force modifiers such as *hart* 'hard' and *leicht* 'lightly', depending on their force intensity (cf. *hart schlagen* 'hit hard' vs #*hart berühren* 'touch hard').

➢ Why is it that for many German speakers a force modifier like *hart* 'hard' or *leicht* 'lightly' is perfectly fine in (1), but less acceptable when a result is specified in (2) (as shown by a preliminary questionnaire study for several manner vs result verb pairs).

2 Force vectors and force paths

We maintain the Neo-Davidsonian view of a verb as a one-place predicate over events, but make the following crucial assumption:

> The event *e* of a force verb is associated to a spatial path PATH(*e*) that consists of vectors representing the forces that the agent of *e* exerts on the patient of *e* at the moment(s) of the run time TIME(*e*) at which the instrument of the agent (like a hammer or a hand) is in contact with the patient (like a nail).

- A **force vector** *f* has three parameters: (i) a spatial origin, (ii) a direction, and (iii) a magnitude (represented by the length of the vector, $|f|$). A zero force vector can be taken as simply a point in space. The spatial origin of a force vector *f* is given by $0f$ (multiplying *f* by scalar 0). A force vector does double duty: its origin represents the position of an object and its direction and magnitude represent the force that that object might exert at that position.
- The **path** *p* of an event *e* is a continuous function from the run time $[t_0,t_1]$ of *e* to force vectors. It represents the sequence of positions that are occupied by the theme or instrument of *e* and the forces exerted by that object at that position, if any. We use $p(t)$ to represent the force vector at time *t*. A *force path* is a path that includes non-zero force vectors in its range (Figure 1a for 'hitting' and 1b for 'pressing'); a pure *spatial path* is a path that has only zero force vectors (i.e. positions) in its range, without specifying force interactions at those positions (cf. Figure 1c for 'into' and 1d for 'in'). A path may be constant, i.e. map every *t* of its domain to the same force or location vector *f* (Figure 1b and 1d).
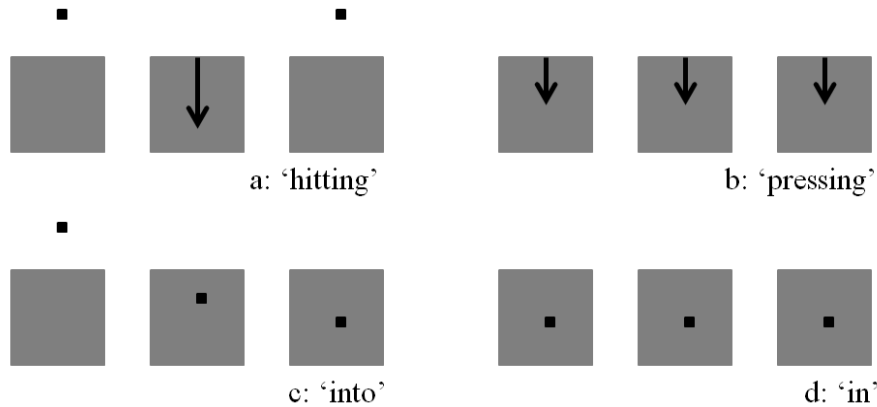

a: 'hitting' b: 'pressing'

c: 'into' d: 'in'

Figure 1: Subsequent 'snapshots' ($p(t_0)$, $p(t_i)$, $p(t_1)$), from four types of (force) paths

3 Forces in the lexicon and in composition

With force vectors built into paths, we can explain the features of force verbs introduced above. Firstly, the lexical differences can be represented through conditions on the path associated to the event, for instance for the verb *schlagen* 'hit':

(3) **schlagen**=$\lambda e.\exists p[p$=PATH(e) $\land$ PUNCTUAL(p) $\land$ INTERNAL(p,TH(e)) $\land$ INTENSIVE(p)]

- **Aspectual distinctions** Punctual force verbs have exactly one moment *t* during the event at which the force vector is non-zero: PUNCTUAL(p) iff $\exists!t\ [|p(t)|{>}0]$. Continuous force verbs (like *drücken* 'push') require that for all moments *t*: CONTINUOUS(p) iff $\forall t\ [|p(t)|\ {>}0]$.
- **Directional distinctions** The vectors of INTERNAL paths point towards the interior of the patient/theme (as in Figure 1a and b). The vectors of EXTERNAL paths point away from the interior (inverses of Figure 1a and b, e.g. with *ziehen* 'pull').
- **Intensity distinctions** Intensive verbs (like *schlagen* 'hit', *reiben* 'rub') require for at least one moment *t* during the event that the magnitude of the force vector is higher than some average force magnitude M_C: INTENSIVE(p) iff $\exists t\ [|p(t)|{>}M_C]$. For non-intensive verbs (like *streicheln* 'stroke', *berühren* 'touch') all moments *t* of the event are mapped to a vector with a magnitude lower than M_C: NON-INTENSIVE(p) iff $\forall t\ [|p(t)|{<}M_C]$.

Secondly, the selectional restrictions some verbs show with respect to prepositions are explained through the need to match the direction of the force vectors of the verb with that of the PP to arrive at a non-empty intersection. We assume that *auf den Nagel* 'on the nail' and *an dem Nagel* 'on the nail' are Davidsonian event predicates defined as $\lambda e[\text{INTERNAL}(\text{PATH}(e),\textbf{den-nagel})]$ and $\lambda e[\text{EXTERNAL}(\text{PATH}(e),\textbf{den-nagel})]$, respectively, i.e. with oppositely directed force vectors. If the PP+V combination is interpreted as an intersection, then *auf den Nagel schlagen* 'hit on the nail' leads to a non-empty intersection because *auf* and *schlagen* specify the same direction, but #*an dem Nagel schlagen* to an empty intersection. The opposite pattern holds for *ziehen*.

Thirdly, the unacceptability of a combination like *hart berühren* 'touch hard' is accounted for by the incompatible magnitude requirements of verb and adverb. The verb *berühren* contains the condition NON-INTENSIVE on its path, while *hart* is defined as the event predicate $\lambda e[\text{INTENSIVE}(\text{PATH}(e))]$. The intersection of the two event predicates then leads to an empty set. The possibility of *leicht schlagen* 'hit lightly' shows that INTENSIVE verbs can be coerced by an adverb to a smaller force intensity.

Fourthly, the contributions made by the PPs in (1) and (2) can be distinguished by the different types of paths associated with them in terms of forces. *Auf den Nagel* 'on the nail' in (1), with the denotation $\lambda e[\text{INTERNAL}(\text{PATH}(e),\textbf{den-nagel})]$, specifies a force path (cf. Figure 1a and 1b). *In die Tür* 'into the door' in (2), however, has the denotation $\lambda e[\text{INTO}(\text{PATH}(e),\textbf{die-tür})]$ describing motion events into the door (Figure 1c), without any specification of forces.

Fifthly, while sentence (1) describes one force-exertion event without specifying the consequences for the nail, sentence (2) relates the hitting event causally to the event of the nail moving into the door. Building on the insights of Wolff (2007) and Copley & Harley (2015), we can say that the force of the hitting event in (1) can be canceled out by other forces working on the nail, e.g. the internal integrity of the material of the door (the forces are then combined under vector addition). In (2) the hitting force is not canceled and it leads to the motion event. In this way, we account for why (2) entails but is not entailed by (1).

Finally, if the compositional interpretation of sentence (2) involves addition of the force vectors of the hitting event with other force vectors in order to compute a result, then this explains why modification by force adverbs is fully acceptable in (1), but less acceptable in (2). The resultative construction requires a computation on force vectors that makes the forces of the initial event inaccessible for modifiers under certain conditions.

4 Conclusion

We have shown that forces figure in the semantics of force verbs in a way that is accessible for adverbs and PPs. This is different from the way forces figure in causal verbs (Wolff, 2007), motion verbs (Geuder & Weisgerber, 2006; Gärdenfors, 2014), or dynamic verbs more generally (Copley & Harley, 2015), where they seem to be either "encapsulated" in force-dynamic interactions or larger force patterns, or where they have a more abstract (less spatial-physical) status.

This suggests that force verbs provide a domain where we can see forces at work in a more direct way, allowing us to study the properties of forces that must form the basis of a general force dynamics of verbs, which encompasses lexical and compositional semantics.

References

Copley, B., & Harley, H. (2015). A force-theoretic framework for event structure. *Linguistics and Philosophy*, *38*(2), 103–158.

Croft, W. (2012). *Verbs: Aspect and Causal Structure*. Oxford: Oxford University Press.

Gärdenfors, P. (2014). *The geometry of meaning: Semantics based on conceptual spaces*. Cambridge, MA: MIT Press.

Geuder, W. & Weisgerber, M. (2006). Manner and causation in movement verbs. *Proceedings of Sinn und Bedeutung* 10, 125-137.

Jackendoff, R. (1990). *Semantic Structures*. Cambridge, MA: MIT Press.

Levin, B. (1993). *English Verb Classes and Alternations*. Chicago: The University of Chicago Press.

Roßdeutscher, A., & Pross, T. (2015). *Representing Force Dynamics at the Syntax-Semantics-Interface*. Presented at the Workshop Formal Semantics Meets Cognitive Semantics, Nijmegen.

Talmy, L. (2000) Toward a Cognitive Semantics: Force Dynamics in Language and Cognition *The MIT Press*.

Van Lambalgen, M., & Hamm, F. (2008). *The Proper Treatment of Events*. Oxford: Blackwell Publishing.

Wolff, P. (2007). Representing causation. *Journal of Experimental Psychology. General*, *136*(1), 82–111.