4

Force dynamics*

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The use of force dynamics to explicate meaning has its origin in cognitive linguistics, particularly in the work of Leonard Talmy. In recent years, despite apparent conflicts between cognitive and formal approaches, force dynamics has also made an appearance in formal semantics. This development has the potential to provide new insight into semantic theory and its relationships to both syntax and conceptual representations.

4.1 Forces for event structure

In this chapter we will examine the use of the notion of force in analysing event structure, as well as in other domains, such as aspect and modality, that flesh out the rationale for the use of forces in language. As with any proposed ontological entity, we want to begin by asking several basic questions: What is a force? Do we need forces? And what will forces cost us in terms of theoretical economy?

4.1.1 *What is a force?*

In defining what a force is, we are not doing metaphysics, but rather naïve metaphysics, reflecting our underlying impression of what is. In this commonsense impression, we can understand forces as inputs of energy that have an origin at which the energy is applied, a direction toward which the energy is applied, and a magnitude which corresponds to the amount of energy applied. These characteristics of forces can be represented by construing forces as vectors. This is a natural way to think of physical forces, and it only then takes a small step to represent other, more abstract forces, namely as an impetus or tendency toward some result (direction) having some intensity (magnitude).

Elements of this definition of force have also been claimed for the commonsense notion of event. Energy, for instance, is routinely claimed for events, although

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change is a competing notion, and perhaps direction is possible in events, in the form of a path. Magnitude is harder to claim for events, though perhaps intensity is the appropriate notion. So at first glance it seems that event talk and force talk are quite similar. However, force talk allows us to do more than event talk in two ways.

The first has to do with modelling *force interaction*: vectors can be summed with each other to represent the interaction of two forces, whereas events cannot be summed to represent the interaction of two events. Significantly, as we will see, configurations of force interactions are often important to lexical distinctions. The second advantage of force talk over event talk is the *ceteris paribus* property of forces: the fact that a force has a result that happens only when '(all) things are equal'. If I push on a cup, all else being equal, the result is that it moves in a certain way or moves to a certain location. All else is *not* equal when something external to the force intervenes through force interaction—so, for example, if the cup is stuck to the table, the force I apply may not result in any change in location of the cup. Note as well that it is analytically clear how a force, modelled as a vector, has a *ceteris paribus* result—it can be recovered from the vector's direction, since the direction is by definition toward the *ceteris paribus* result. In contrast, it is not at all analytically clear how an event has a *ceteris paribus* result.

Where such interaction and *ceteris paribus* characteristics are seen, it is thus a reasonable hypothesis that force dynamics is being recruited at some level.

4.1.2 *Forces are needed*

Our second question was whether we need forces in our ontology to explain linguistic phenomena. We will see a number of cases where forces are needed in this chapter, but to begin with here are two. Some of the clearest cases in which forces are needed, and in fact the first ones to be addressed, have to do with force interaction. Cognitive linguist Leonard Talmy was the first to systematically take up the idea of force dynamics as explanatory of the meanings of certain linguistic expressions (Talmy 1972*b*, 1976, 1985*a*, 1988), building off Langacker (1987). For Talmy, forces are seen as occurring within events, where force-dynamic relations are but one particular relationship between participants in an event; others could be (visuo)spatial, perspective-related, possessive, and so forth. So, for example, consider the sentences in (1).

(1) a. The ball was rolling along the green.
    b. The ball kept (on) rolling along the green.

Talmy's insight about the contrast in (1) is that (1b) highlights an opposition between two forces or tendencies (where 'force' and 'tendency' are equivalent notions; i.e., they are ultimately inputs of energy toward a *ceteris paribus* outcome). That is, in (1b), the ball has a tendency that is being overcome by an external force. This tendency of the ball's could be a tendency toward rest, in which case the external force could be the wind pushing the ball. Alternatively, the ball's tendency could be toward motion, in which case the opposition could be, e.g., from the stiffness of the grass. In either case force is what distinguishes (1a) from (1b).

The ability to have an analysis for verbs of maintaining such as *keep* is a significant benefit of the force dynamic approach, since using Davidsonian event arguments runs into problems for the decomposition of such predicates, as Copley and Harley (2015) argue.

In a strictly event-theoretic analysis, one could easily analyse *keep* as involving an external causing argument such that the meaning of *keep* is 'cause to stay'. The question then is how to analyse *stay* without using force dynamics.

As Copley and Harley point out, there is no easy way to decompose the meanings of such verbs with ordinary Davidsonian event arguments; the problem lies in the impossibility of distinguishing *stay* from both *be* and *go (to)* at once. If *stay* is distinguished from *be* by having a causing event, *stay in the room* looks like *go to the room*: $\exists e_1, e_2 : [e_1 \text{ CAUSE } e_2]$ and $[\![\text{in the room}]\!](e_2)$. If on the other hand one tries to distinguish *stay* from *be* simply by giving *stay* a presupposition that *p* was true beforehand, that is unsatisfactory as well, since it is not expected that the presence or absence of a presupposition would change the Aktionsart of the predicate, and *stay* and *be* do not have the same Aktionsart. While *be* is stative, *stay* is not, as can be seen from the fact that *Juliet stays in the room* has only a habitual reading.

A force-dynamic perspective thus allows us to decompositionally analyse lexical meanings in verbal predicates that would be impossible, or at least very difficult, to decompose without forces.[1] With force dynamics, however, *stay* can be distinguished from *be* because *stay* involves a force while *be* does not, and *stay* can be distinguished from *go* because there is no change.

[1] Jackendoff (1987) proposes a primitive STAY subtype of his 'primitive conceptual category' EVENT, but without proposing further decomposition. Another non-decompositional approach is to say that staying eventualities are a kind of hybrid of events and (true) states, with some properties of each, as in Maienborn's 'Davidsonian states' (e.g., Maienborn 2007*b*, this volume).

Another reason forces are useful is that they allow us to make basic distinctions between *cause* and other verbs related to causation, such as *enable*, and *prevent*, as shown in (2) (Wolff 2007).

(2) a. *x cause (y to) p*: *x*'s stronger tendency toward *p* opposes *y*'s tendency away from *p*.
b. *x enable (y to) p*: *x*'s tendency toward *p* is in the same direction as *y*'s tendency toward. *p*
c. *x prevent y from p-ing*: *x*'s stronger tendency away from *p* opposes *y*'s tendency toward*p*.

While a simple causal relation between events (e_1 CAUSE e_2) can be used for *cause* as in (2a), it cannot be used for *enable* and *prevent* in (2b,c). And while a more inclusive causal relation such as *lead to* with event relata (Ramchand 2008*b*, 2017) can be used in decompositions of both *cause* and *enable*, it cannot easily distinguish them. That is, one can decompose *cause* as something like '*x*'s action e_1 led to e_2', but this paraphrase could equally apply to *enable*. Worse, *lead to* cannot really be used in a decompositional analysis of *prevent*. The reason is that *lead to p* would have to specify *x*'s force toward *p*, while *prevent y from p-ing* specifies *x*'s force away from *p*; this conflict would be difficult to overcome compositionally. A decompositional difference between *cause* and other causal verbs is thus not easy to achieve unless something like force dynamics is utilized at some level.

4.1.3 *Forces come for free*

Our third question was how much it would cost us to posit forces in the ontology. There is evidence that force-dynamic representations are already needed in cognition, which means that there is no particular extra cost involved positing them.

First, there is evidence that we perceive forces, in a low-level sense. The contrary has been long argued: Hume's influential theory of causation took forces to be among the things that could not be perceived directly.[2] Instead, for Hume, regular dependencies are all we can perceive, and it is these that lead us to infer a causal relation. However, as Wolff and Shepard (2013) convincingly argues, Michotte's (1946) findings that anomalous temporal gaps and directions of movement interfere with impressions of causation support a force-dynamic view, contrary to Michotte's own Humean conclusions. The reason is that time

[2] See Wilson (2007), Massin (2009) for recent discussion on the (non-naïve) metaphysics of forces, which we will not get into here.

and direction are inherent to forces but not to simple dependencies, so if temporal and directional anomalies perturb our impression of causation, it can only be because we are using force dynamics to infer causation.

This point is in line with the idea that we perceive 'felt forces' (Wilson 2007). Robles-De-La-Torre and Hayward (2001) show that force perception can compete favourably with other kinds of perception. Moving your fingers over a bump, there are two cues that allow you to perceive the bump: the geometry and the force of the bump pushing back on your finger. What they found was that if these cues are dissociated such that there is a geometrical depression but the force of a bump, subjects perceive a bump. Furthermore, force-dynamic information can be recovered from information about kinematics alone ('kinematic specification of dynamics' or 'inverse dynamics'), and is difficult to ignore or obscure. For example, a person lifting a heavy box cannot by their motions deceive the onlookers about the weight of the box (e.g. Runeson and Frykholm 1981, 1983); see Wolff and Shepard (2013) for more on research in this domain.

Moreover, there is evidence that the information about forces can be packaged in an abstract way to relate to language, as we would expect from Talmy's work. In a series of experimental studies (Wolff and Zettergren 2002, Wolff 2006, 2007, Wolff and Shepard 2013, Wolff and Barbey 2015), Wolff and colleagues presented subjects with animations depicting force-dynamic configurations and asked them to determine whether a particular configuration matched CAUSE, ENABLE, or PREVENT. And indeed, direction in one dimension and relative magnitude were the important considerations used by subjects in determining whether such predicates could be described as these predicates. Absolute magnitude, on the other hand, was of no use in this task, and subjects could not even reliably distinguish different absolute magnitudes (Wolff and Shepard 2013).

4.2 Energy, change, and the word *dynamic*

A note on terminology before we go on to assess force-dynamic theories of meaning: since forces are inputs of energy, we immediately need to distinguish energy from change, which has not always been done explicitly in event semantics. Change and energy are not the same, as evident in our intuitions about what it is to exert a force; one can easily exert a force (an input of energy) against an object that does not move, for instance. This distinction is what motivates, for instance, Croft's three-dimensional model of verb meaning (Croft 2012, 2015), with time as the first dimension, change in qualitative states as the

second dimension, and force or energy as the third dimension. However, as Bohnemeyer and Swift (2006) note, there is a close connection between change and energy. In some sense change cannot happen without energy.

The close connection between energy and change can be seen in microcosm by looking at the use of the word 'dynamic(s)' (Massin 2009, Copley and Harley 2015), which can mean either 'characterized by change' or 'characterized by energy'.

The 'change' meaning of the term 'dynamic' can both be found throughout the linguistics literature. For example, Bohnemeyer and Swift (2006): 'we propose the basic meaning of dynamicity is change'. Beavers (2008*b*: 245) defines dynamic predicates as 'predicates that involve some "change" or potential change in one participant'. Fábregas and Marín (2014), while differentiating eventivity and dynamicity, treat 'eventivity' as having a designated syntactic process head (in the sense of Ramchand 2008*b*), while 'dynamicity' refers to change, that is, '(abstract) movement … in some quality space.' Maienborn uses 'dynamic' apparently to refer to those predicates that either do not have the subinterval property or have a lower bound on their subinterval property, i.e., non-states (Maienborn 2007*b*). This could be seen as a version of using 'dynamicity' to refer to change, as in practice such a definition excludes predicates such as *sleep* and *stay*.

The 'energy' meaning, however, also has its proponents. 'With a dynamic situation, … the situation will only continue if it is continually subject to a new input of energy … (Comrie 1976: 49); 'The bounded nature of events can be derived from their dynamicity. Events require a constant input of energy.' (Smith 1991: 36). Bach (1986) reserves 'dynamic' for a subclass of statives such as *sit*, *lie*, which would seem to indicate that he is not using it to refer to change. Beavers (2011: 338) also seems to distinguish dynamicity from change in this way: 'I assume that change can only be encoded in dynamic predicates. But which dynamic predicates involve changes … ?'[3] Copley and Harley (2015: 104) allude to usage in physics, which distinguishes dynamics (the study of energy) from kinematics (the study of motion, which is one kind of change).

Now that we are representing forces as distinct from changes, a terminological distinction between the two becomes more important. My own preference is to reserve 'dynamic' for energy, but in any case the choice should be made explicit.

[3] If dynamicity is about energy, and events are about change, a phrase such as 'dynamic event' is sensible, but trivial, in that all events are dynamic, because all cases of change involve forces. However, not all cases of force involve change, so not all cases of dynamicity are cases of eventivity.

4.3 Cognitive linguistic force-dynamic theories

In this section we will look at some of the major components of force-dynamic theories within the cognitive linguistic tradition where force dynamics first came to the attention of linguists. The first several components (force opposition, the existence of two possible temporal relations between force and result, and intrapersonal forces) are due to Talmy and are discussed in the first part of the section. The second part of the section discusses the use of forces for modality, proposed by Talmy for root modals and Sweetser (1984, 1990) for epistemic modals, alongside a critique by Portner (2009). In the final part of the section, the usefulness of forces for causal chains is addressed, drawing on work in the cognitive linguistic framework by William Croft, as well as similar points made in the formal literature.

4.3.1 *Three components of Talmy's theory*

The main organizing principle of Talmy's approach to force dynamics for meaning is *force opposition,* a special case of force interaction. For Talmy, all force-dynamic meanings expressed in language necessarily involve an opposition between two forces that are in opposite directions. Each of these two forces is related to one of two entities that are either expressed in the sentence or understood from the context. One of these entities, the Agonist (usually the agent), is 'singled out for focal attention' (Talmy 2000: 413), while the other entity, the Antagonist, is considered only insofar as it impacts the Agonist. What is at issue is whether the force associated with the Agonist overpowers the force associated by the Antagonist, or conversely, is overcome by it. In (2b), for instance, the Agonist is the ball, and the Antagonist is the other entity (the wind or the grass), which in this case is provided by the context, and what is at issue is the whether the ball's tendency is stronger (greater magnitude) than the Antagonist force.

Keep, for Talmy, does not by itself specify which opposing force is stronger. We can see this more clearly by expressing the Antagonist explicitly, as in (3a) and (3b):

(3) a. The ball kept rolling because of the stiff wind.
b. The ball kept rolling despite the stiff grass.

Because of and *despite*, in addition to introducing the Antagonist, indicate which of the two tendencies is stronger: the Antagonist's tendency, in the case of *because* in (3a), and the Agonist's tendency, in the case of *despite* in (3b).

Talmy's requirement for force opposition works in many cases, but in other cases it is something of a stretch. Talmy sees opposition in (4), where the logs are the Agonist and the Antagonist is the earth, whose tendency to oppose the rolling of the logs is removed.

(4) Smoothing the earth helped the logs roll down the slope.

However, Jackendoff (1990) and Wolff and Song (2003) argue that such predicates are more naturally understood as involving a concordance rather than an opposition between forces. Thus the second participant is not literally antagonistic to the Agonist. Accordingly, in (4), the 'Antagonist' (which no longer antagonizes on this analysis) is the agent doing the smoothing, who provides an additional force toward or in support of the logs' tendency to roll down the slope.

A second important component to Talmy's theory is the point that there are two different *temporal relations* between a force and its result. For Talmy, 'onset' causation is where the result begins after the force is applied, as in the sentence *The stirring rod's breaking let the particles settle*, while 'extended' causation is where the result happens as the force is applied, as in the sentence in (3b). Such a distinction had been presented in Shibatani (1973*b*) as 'ballistic' versus 'controlled' causation and, as pointed out by Jackendoff (1990: 138), a similar distinction had been independently discussed by Michotte (1946) as 'launching' versus 'entrainment'; I will use Michotte's terminology since it is the earliest.

While entrainment, where the cause is cotemporal with the result, is not strictly excluded from an event-theoretic perspective, in practice there are enough difficulties in applying the distinction to Davidsonian verbal predicates that the possibility was never noted in event-theoretic approaches. (We will return to this point in Section 4.5.4.3 below.)

A third significant component that Talmy introduces is *intrapersonal forces*, which provide a way to understand effort or exertion of animate entities in a force-dynamic way. As Talmy notes, physical force manifestations of animate entities are generally understood to arise from their minds rather than from their physical properties alone. So, for example, while in (5a), the dam's Agonist force is understood to arise from its solidity, etc., the man's Agonist force is understood to arise not only from his physical properties. Rather, he is consciously and volitionally 'maintaining the expenditure of effort' as 'a continuously renewed exertion' to counter the Antagonistic force of the crowd (Talmy 1988: 71; 2000: 433).

(5) a. The new dam resisted the pressure of the water against it.
b. The man resisted the pressure of the crowd against him.

For Talmy, exertion reflects a split of the psyche into two parts, a basic or default part that is 'repose-oriented' and a more peripheral one that is 'goal-oriented'. These parts can play the role of Agonist or Antagonist. Thus, not only do force-dynamic configurations represent physical and psychosocial influences, but they can also represent influences in opposition that are conceived of as occurring within a single mind, i.e., 'intrapsychological' forces. Though Talmy does not say so in so many words, it is clear that on this view animate entities need to have a certain—though not unlimited—*ability* to determine the magnitude of the physical force they apply toward the goal. This is one way that animate entities can be distinguished from inanimate entities; the latter have no ability to control the magnitudes of the physical forces that arise from them.[4]

Using this understanding of exertion, a predicate such as *try* can be construed with the physical Agonist force being the result of exertion on the part of the subject. Additionally, the Agonist force for *try* would not necessarily be stronger than the Antagonist force, that is, success would not necessarily occur. So for Talmy, *trying* to do something and *causing* something to happen differ in two respects: whether there is exertion and whether the Antagonist force is stronger than the Agonist force.

It should be noted that Talmy extends the notion of exertion to predicates that arguably do not necessarily refer to exertion. For example, while he also treats *manage to* and *finally* as involving exertion, this cannot be correct, as both can be used in situations where there is no exertion on the part of the subject, e.g. *John managed to break/finally broke his leg*, both perfectly acceptable even when John is assumed not to have wanted to break his leg, therefore could not have exerted himself to do so (Baglini and Francez 2016). Compare these to *John tried to break his leg*, which clearly indicates that John wanted to break his leg. Nonetheless, for cases that do involve exertion, Talmy's insight provides a useful characterization.[5]

4.3.2 *Modality with forces: Talmy and Sweetser*

Talmy proposes that modal sentences can make reference to forces. He argues that some modals, such as *can* of ability in (6), involve physical forces (these would correspond to the modals that Kratzer 1991 argues to involve circumstantial model bases).

[4] Animate entities also have an ability to control the *direction* of the physical forces that they apply, namely, that such forces are directed toward the goal the entity has in mind. This point relates to *teleological capability* (Folli and Harley 2008).

[5] In the formal literature, Giannakidou and Staraki (2013) characterize the exertion inherent to *try* as a force function in the sense of Copley and Harley (2015).

(6) The ball can't sail out of the ballpark with the new dome in place.

Here again we can see a force opposition, with the ball's tendency to leave the park opposed by a force exerted by the dome. The *can* of ability conveys that the ball's tendency is stronger than the force exerted by the dome.

Talmy also treats deontic readings of modals as force-dynamic, where the forces being referenced are not physical but 'psychosocial,' that is, reflecting interpersonal dynamics of desires, intentions, and authority. ' "[W]anting" ... seems to be conceived in terms of a kind of psychological "pressure," "pushing" toward the realization of some act or state' (Talmy 2000, vol. 1: 430). The content of the desire provides the direction of the force, and relative authority (conceived of as a kind of ability) provides the relative magnitudes of the forces. So for instance, on a deontic reading, *may* reflects both a desire on the part of the Agonist subject for the complement of *may*, as well as a non-impingement of a potentially stronger Antagonist psychosocial force; *must*, on the other hand, reflects a non-desire (or no particular desire) on the part of the Agonist subject, with a stronger Antagonist psychosocial force. In neither case does the Antagonist—the authority—have to be explicitly mentioned in the sentence.

As for epistemic modal meanings, these have also been proposed to be amenable to force-dynamic analysis by Eve Sweetser (1984, 1990). Sweetser proposes that modals should be viewed as 'semantically ambiguous between our sociophysical understanding of force and some mapping of that understanding onto the domain of reasoning' (1990: 58). Epistemic readings of modals make reference to *epistemic forces* applied by a set of premises, which compel or make possible or plausible a conclusion, namely the propositional argument of the modal. While root modal meanings describe force dynamic patterns in the world, epistemic modal meanings describe force-dynamic patterns in the realm of reasoning. 'As descriptions, sentences describe real-world events and the causal forces leading up to those events; as *conclusions*, they are themselves understood as being the result of the epistemic forces which cause the train of reasoning leading to a conclusion' (1990: 65).

Portner (2009), in a critique of Talmy's and Sweetser's force-dynamic perspective on modals, correctly points out that these views are not nearly as explicit as Kratzer's proposals (e.g., Kratzer 1981, 1991, 2012) for modality. One specific problem is the intensionality inherent to modality: the fact that generally, modal sentences do not entail their complement. Where, Portner asks, is this fact explained in the force-dynamic perspective?

This is an appropriate question. For a sufficiently worked-out theory, an answer to this question would surely lie in the *ceteris paribus* property of forces—the fact that forces themselves are in a sense intensional, since the result of a force does not necessarily obtain if other forces block it. However, there is an

additional wrinkle. As we have seen, Talmy treats physical forces and intentions in exactly the same way, and Sweetser apparently treats her epistemic forces in the same way as well. Still, while a simple physical force has a result that is a single outcome, not a set of outcomes, an intention or an epistemic force would have to somehow embed a proposition, which would be (at the very least) a set of outcomes, not a single outcome. Gärdenfors seems to recognize this issue when he defines goal vectors (representing an animate entity's intentional goal) as being 'more abstract' than movement vectors (2014: 64). The solution to this problem will be to find a way to get propositions into force dynamics, by somehow distinguishing between propositional and non-propositional results. So Portner's critique, while entirely accurate about existing theories, is not in principle unaddressable, provided that a more sophisticated taxonomy of forces could be made.

Portner also wonders whether Sweetser's 'epistemic forces,' when made sufficiently explicit, would not reduce to logical relations, either classical or probablistic. This may be so, but even if so, it is not a problem for Sweetser. In Sweetser's view, the relations of logical consistence and necessity that are used in Kratzer's possible worlds analysis—for root modals as for epistemic modals—are essentially epistemic relations between believed propositions, rather than physical or causal relations in the world. Thus the problem is not in using such relations for epistemic modality, but in using them for root modality.

And actually, there is a better formal counterpart to Sweetser's epistemic forces, which may shed a brighter light on the analogy between physical and epistemic forces. In Sweetser's force-dynamic perspective on processes of reasoning we can see an echo of the insight according to which all utterances are seen as 'context change potentials,' which gave rise to dynamic semantics around the same time (Kamp 1981*b*, Heim 1982, Groenendijk and Stokhof 1991). In dynamic semantics, 'meaning is seen as an action' (van Eijck and Visser 2012), and indeed processes of reasoning are sometimes explicitly treated with a *cause* relation (e.g. Lascarides and Asher 1991). Moreover, as Copley and Harley (2015) argue, there is a very direct equivalence along the lines of Sweetser's proposal between force dynamics and the subset of dynamic approaches that hinge on 'default' or 'defeasible' inferences (Lascarides and Asher 1991, Asher and Lascarides 2003, Veltman 1996). This is the *ceteris paribus* property again: just as forces lead defeasibly to a situation in the world (as other, stronger forces can block this from happening), so too utterances can lead to default information states, but default conclusions are defeated if there is information to the contrary.

4.3.3 *Causal chains: Croft and others*

On the heels of Talmy's initial foray into force dynamics, William Croft's work (e.g., Croft 1991) extended the usefulness of force dynamics as an organizing principle for argument structure. Here we will trace arguments by Croft and others that force-dynamic causal chains are relevant to event structure in the argument realization of thematic roles such as agent and patient, as well as in cases of indirect causation and psych verbs.

Argument realization is the question of which participant in an event is associated with which grammatical position in a clause (see Levin and Rappaport Hovav 2005 for a detailed overview). A very common way to answer this question is through assigning thematic roles such as Agent and Patient, and relating those roles to grammatical positions. In theories that offer conceptual criteria for such thematic roles, these criteria can be causal in nature; for example, in Dowty's (1991) Agent and Patient 'proto-roles', for example, a prototypical Agent 'causes an event or state' and a prototypical Patient is 'causally affected by another participant.' However, such criteria on their own may not straightforwardly capture the fact that patients need not change, in verbs of surface contact and motion such as *hit* in (7) (Levin and Rappaport Hovav 1995). It is not entirely clear whether the table in (7) is 'causally affected' in terms of change.

(7) Dashiell hit the table.

If instead the causal structure of the event is understood systematically in force-dynamic terms, as proposed variously by Langacker (1987), Croft (1991), Jackendoff (1990), Croft (2012), Levin and Rappaport Hovav (1995), Song and Wolff (2003), Wolff (2003), Beavers (2011), Warglien *et al.* (2012), Gärdenfors (2014), among others, we can understand agents as being the 'source of energy' (as in Langacker 1987, vol. 2: 292 and patients as being the recipients of that energy, so that cases like (7) are explained.

Moreover, causal chains, as instantiated in a force-dynamic framework, impose a conceptual organization on thematic roles that is reflected in the syntactic structure, namely that of the transmission of force relationships between participants (Croft 1991, 2012, 2015). For example, not only do agents initiate the force and appear higher in the structure, and patients receive the force transmission and appear lower in the structure, but instruments, which are an intermediate part of the force transmission, occur in an intermediate part of the syntactic structure.

In addition to thematic roles, force-dynamic causal chains are useful as part of an explanation as to why and how language distinguishes between direct and

indirect causation, especially regarding the lexicalization of verbs. For instance, (8a) cannot really be used to describe a situation where Tate opens the window, which allows the wind to open the door. Likewise, (8b) is perfect in that situation but is odd in a situation where Tate opens the door in the normal way.

(8) a. Tate opened the door.
b. Tate caused the door to open.

Distinctions between simpler and more complex event structures are therefore grammatically significant (and see, for instance, Levin and Rappaport Hovav 1999, 2004, Ramchand 2014*a*, and Ramchand's and Siloni's chapters in this volume). Roughly, the more complex the event structure, the more indirect the causation. As Levin and Rappaport Hovav (1999) point out, temporality is relevant to the notion of event complexity as well; simpler events involve temporal overlap (as in Tate's force and the door opening in (8a)) while more complex events do not (Tate's action in (8b) preceeds the opening of the door). Periphrastic causatives can also themselves be sensitive to direct versus indirect causation (Kemmer and Verhagen 1994, Verhagen and Kemmer 1997, Vecchiato 2003).

It is certainly possible to represent these causal chains with causation understood counterfactually, as in Dowty's (1979) version of Lewis's theory of causation. However, as Copley and Wolff (2014) argue, if causation in verb phrases is based on a counterfactual theory of causation such as Lewis's, it is not really clear why grammar would so often distinguish indirect causation from direct causation. This is because counterfactual theories of causation (like all dependency theories of causation, see Section 4.4.3 below) reduce causation to a kind of correlation or dependency, so that any difference between direct and indirect causation is neutralized. Moreover, temporal overlap is irrelevant to correlations, without world knowledge of physics to ground it in—which is essentially admitting that a force-dynamic component is necessary. The need for causal relations other than *cause* (e.g., *enable, help*) to account for different kinds of instruments' participations in causal chains (Koenig *et al.* 2008) also points toward the need for force dynamics.

Croft, for his part, argues that two different kinds of causation are both relevant to causal chains: one with participants as relata, and one with events as relata. In Croft (2012, 2015) he addresses this issue by breaking the event down into subevents, each with their own participant and state or change in state of the participant, all linked by force-dynamic causation.

Finally, using force-dynamic causal chains in verbal meanings should provide reasons why certain predicates have crosslinguistically variable and atypical linguistic realizations. Croft (1993, 2012) argues that mental events such as

emotion, cognition, and perception can be construed as transmission of force in either of two directions: an experiencer exerting a force to direct their attention to a stimulus, or a stimulus providing a force that changes the mental state of the experiencer (he also proposes a third, state-based construal; cf. Chilton (2014: 85) who claims that all perception involves forces, at least metaphorically). Perception is in any case a very direct kind of causation (Higginbotham 1983, Kemmer and Verhagen 1994); see also Vecchiato's (2003) 'occult' causation). The relevance of eventuality type and directness of causation again suggests force dynamics.

4.4 Can there be forces in a formal theory?

The fact that theories of force dynamics in language arose within cognitive linguistics might seem to preclude the use of forces in formal theories. However, as Hamm *et al.* (2006) argue, there is no real contradiction between cognitive and formal approaches to semantics, despite some apparent conflicts. We disentangle three such apparent conflicts here: the nature of meaning, the syntax–semantics interface, and intensionality in the treatment of possibilities and causation.

4.4.1 *The nature of meaning*

The cognitive linguistic viewpoint, in which force-dynamic theories first arose, treats meaning as non-propositional, subjective, and analogue (Lakoff and Johnson 1999). Meaning 'cannot be reduced to an objective characterization of the situation described: equally important … is how the conceptualizer chooses to *construe* the situation and portray it for expressive purposes' (Langacker 1990: 5). Meaning's connection to the world is thus mediated through our construals of the world, and such construals correspond to the world to the extent that we are 'in touch with reality' (Johnson 1987: 203) and are successful in achieving a communicative 'meeting of minds' (Warglien and Gärdenfors 2013).

On the other hand, formal, model-theoretic semantics—traditionally, in any case—follows Frege and Lewis in treating meaning as referring to the world in a direct, objective way, rather than a subjective way. Entities are members of sets, and participate in relations and functions, constructing propositions that are related to truth values by means of contextual indices. Thus meaning is propositional, objective, and digital (true/false, or in a set/not in a set), and it is fruitless to try to understand meaning in terms of psychological and psychosocial phenomena (Lewis 1970) or in terms of one's own subjective idea (Frege 1948).

The question for us is whether the considerable daylight between these two views is pertinent to the use of force dynamics at the syntax–semantics interface. There are in fact two separate, orthogonal issues. First, what does meaning do? That is, does it build construals of the world such as force-dynamic representations, or does it make reference to the world directly, as Frege and Lewis argue? And second, need meanings have 'analogue' representations to capture the richness of conceptual nuance as in the interactions of forces, or can they be represented using 'digital' representations?

As for the issue of what meaning does, while all formal semanticists have adopted the idea of function-driven compositionality from Frege, they may or may not also be willing to accept that meanings directly refer to the world, without any conceptual structure mediating the relationship. It is perfectly possible to be a formalist and yet believe, as Ramchand (this volume) puts it, that 'facts about situations in the world feed, but underdetermine the way in which events are represented linguistically.' Work by Kamp and others in Discourse Representation Theory is the most robust example of formal but conceptual approaches; see Hamm *et al.* (2006), as well as Asher's 'natural language metaphysics' as compared to 'real metaphysics' (Asher 1992: 7). In any case the question has not been a major concern for many in the generative tradition, especially in North America (though see Jackendoff, e.g. 1983, 1997, for an exception). In short, as Hamm *et al.* (2006) suggest, this issue could (and should, they argue) be resolved in favour of conceptually-mediated meaning without undermining formal approaches.

The second question is whether formal machinery is appropriate for rich conceptual schemas such as those involving forces. On the cognitive linguistics side, there is an impression that force-dynamic representations, among others, are too fine-grained to be shoehorned into logical representations: Sweetser (1990), seeing a dichotomy between formal and conceptual approaches, places her partly force-dynamic theory on the side in which meaning has its basis in human cognitive experience. For his part, Gärdenfors sees logical denotations of linguistic expressions as involving 'a vicious circle of symbolic representations' (Gärdenfors 2014: 164), much as if such denotations were intended to stand on their own without *any* link to either the world or to a conceptual level; this has never been the claim of any formal semantic proposal.

The key question is whether 'analogue' representations of forces can be mapped to 'digital' representations of forces; this is a special case of the broad question of whether the 'messy' real world can be mapped to 'symbolic and categorical' linguistic expressions (Ramchand, this volume). There are several ways to answer this question in the affirmative. One way is already familiar from digital music and photography: namely, that a digital system with sufficiently small divisions is effectively indistinguishable from an analogue system. A formal representation of forces as vectors applied throughout time, for instance along

the lines of Zwarts and Winter (2000), is a possible realization of this kind of solution, as we will see below in Section 4.5.1. Another answer is to follow Talmy (2000) and Zwarts (2010), etc., in directly representing force-dynamic relations such as *support*, *attach*, and *oppose* as relations between entities, with or without the language having access to the underlying forces.[6] Finally, as we will see below in the theories of van Lambalgen and Hamm, and Copley and Harley, it is possible for language to represent a simplified or abstract version of force vectors, leaving various details to the conceptual level. Whichever method is used, there is no principled problem to representing forces in a formal system.

4.4.2 *The syntax–semantics interface*

An additional issue that arises when considering how force-dynamic approaches can be incorporated into formal (generative) work at the syntax–semantics interface is the difference in how cognitive and formal approaches treat syntax. As we have noted, within the general cognitive approach, force-dynamic meanings are understood as residing within a conceptual structure. Semantics is to be derived from, or indeed identified with, this conceptual structure. Within the cognitive linguistic tradition of force-dynamic approaches, there is considerably more interest in investigating the role of grammatical and lexical material in determining this conceptual structure, than in relating such a structure to a formal, autonomous syntactic structure; syntax can be seen as being rather unimportant. Conversely, in generative approaches, as Croft (2012: 28–30) puts it, the mapping between syntax and semantic/conceptual structure is less direct than in cognitive approaches, and the mapping itself is more of an object of study.

Gärdenfors treats conceptual structures as providing 'constraints on what syntactic constructions are possible or likely' (Gärdenfors 2014: 72) but backgrounds syntax because 'syntax is required only for the most subtle aspects of communication—pragmatic and semantic features are more fundamental for communication.' (Gärdenfors 2014: 71).[7]

[6] A similar relational approach to force dynamics has also been used in machine classification of events from videos (Siskind 2000, 2001, Fern *et al.* 2002). For example, *pick up* is understood as describing an event in which the agent is not supported throughout the event, the patient is supported throughout the event, and the patient transitions from being supported by, e.g., a table to being supported by the agent.

[7] He also denies a mapping between sentences and propositions, on the grounds that 'the meaning of a sentence to a large extent depends on its context,' (Gärdenfors 2014: 176); I can only see this, and similar objections, as a misunderstanding of modern formal theories of semantics and pragmatics, in which context-dependency is easily implemented.

Talmy is interested in working out the roles of grammatical and lexical material in determining conceptual structure: 'Together, the grammatical elements of a sentence determine the majority of the *structure* of the [conceptual representation], while the lexical elements contribute the majority of its *content*.' (Talmy 2000, vol. 1: 21); and again, 'The closed-class forms of a language taken together represent a skeletal conceptual microcosm.' (Talmy 2000, vol. 1: 179). Talmy does refer to syntactic structure, but it is a syntax of the most basic sort, even at times a flat structure within a clause. While in other material he does admit the possibility of a mismatch between conceptual and syntactic structure (e.g., Talmy 2000, vol. 1: 265), syntax does not play a prominent role in his work on force dynamics.

Croft works within a Construction Grammar approach in which there is no strict division of semantic and syntactic components; rather, each particular construction is a stored meaning–form mapping. This said, Croft's conclusions are sometimes not far off generative approaches, particularly the insight that each participant has its own subevent in the causal chain, a conclusion that has been reached independently in neo-Davidsonian generative approaches for both syntax and semantics (see Lohndahl, this volume).

There is much merit in the heuristic that conceptual structures, if properly understood and structured, should be expected to take over some of the functions of purely formal properties and features; indeed, modern decompositional approaches to verb meaning (Hale and Keyser 1993, Kratzer 1996, 2005, Folli and Harley 2005, Ramchand 2008*b*) are not such distant cousins to this idea. From a generative point of view, then, Talmian force dynamics is best viewed as a starting point with which to construct possible or plausible meanings, with work still to be done at the syntax–semantics interface to determine the compositional details in specific cases, and how much of the meaning is available to manipulation by the grammar.

Further, however, force-dynamic perspective has great potential to simplify logical forms, and thereby to clarify and constrain the syntax–semantics interface. This is because, as we saw in Section 4.1.1 above, forces can do more than events, due to the possibility of force interaction and the *ceteris paribus* property, so that complexity that otherwise would have to be spelled out elsewhere in the logical form (or, e.g., in definitions of theta roles) can reside instead in conceptually plausible definitions of forces and how they behave. This can be seen most clearly in the work of Copley and Harley, which we will discuss in Section 4.5.4 below.

4.4.3 *Intensionality: possibilities and causation*

A third issue separating cognitive linguistic and formal approaches has to do with intensionality. As we have seen, the *ceteris paribus* property of physical forces introduces intensionality, since the result of the force does not necessarily come to pass. We have seen as well (Section 4.3.2) that there are two different kinds of intentionality which seem to be conflated in cognitive linguistic approaches: one in which the result is a single outcome (ordinary physical forces), and one in which the result cannot be smaller than a set of outcomes (at least intentions, perhaps others). These outcomes are possibilia, but they are small, closer to situations than to worlds, and the directedness of the force toward the outcome or set of outcomes is somewhat basic to the idea of a force and not further analysed. Do these facts pose a problem for the representation of forces in formal approaches? That is, do forces present a conflict with possible worlds?

Possible worlds have a distinguished provenance in philosophy, going back to Leibniz's account of necessity and possibility as involving universal and existential quantification, respectively, over a set of possible worlds. The idea of possible worlds was utilized and expanded to great success in the modern development of modal logic (see Ballarin 2010 for an overview), and further cultivated in David Lewis's foundational works on possibility, causation, and counterfactuals (e.g., Lewis 1968, 1977, 1975), as well as Stalnaker (e.g., 1968, 1981). It is this perspective that formal linguists have largely inherited, through the lens of important early works such as Dowty (1979), Kratzer (1991), and Kratzer (1986).

The overwhelming explanatory success of this perspective is such that in formal semantics, modality is virtually always identified with the mechanism of quantification over possible world arguments. As we have seen above in Section 4.3.2, however, this picture is manifestly at odds with Talmy's view of modals, in which modal auxiliaries such as *can* and *must* are essentially force-dynamic in nature. To incorporate forces into the ontology, this apparent conflict must be resolved.

This conflict parallels a long-standing philosophical debate over the nature of causation. Theories of causation can be divided into *dependency* (or 'make a difference') theories and *production* (or 'process', 'generative', or 'mechanistic') theories, the latter including force-dynamic theories (Copley and Wolff 2014).

Dependency theories define causation as being fundamentally built on a dependency between events. The statement *A causes B* is consequently defined in terms of a dependency of the occurrence of a B-event on the occurrence of an A-event. The particular kind of dependency can be one of logical dependency (e.g., Mackie 1974), counterfactual dependency (e.g., Lewis 1977), probability

raising (e.g., Suppes 1970), or intervention (e.g., Pearl 2000). Production theories, on the other hand, understand causation as involving a mechanistic relationship between participants, either as a configuration of forces (e.g., Wolff 2007), a transmission of energy (e.g., Dowe 2000), or a transference of some other quantity (e.g., Mumford and Anjum 2011).

Dependency theories, in short, view causation in terms of possibilities, in the sense that possible worlds or situations are primitive, and causation is defined in terms of propositions which are predicates of these possible worlds. Production theories, on the other hand, take causal concepts such as force and transmission of energy to be primitive, with the forces themselves defined as being directed toward possibilia. The relevance of the debate on causation to our question about intensionality is therefore that causation and modality are 'two sides of the same coin,' as Ilić (2014) puts it. Either causation can be derived from possibilities, as in the dependency perspective, or possibilities (in the sense of possible courses of events) can be derived from causation, as in the production perspective. The production perspective does require primitive possibilia, but organizes them into a course of events (a 'world') only through forces; the courses of events are not themselves atomic.

Both dependency and production theories are, or can be made, powerful enough to describe anything the other kind of theory can, even if some phenomena are better explained with one kind of theory than the other. This point might not at first be obvious; there is often a suspicion that forces are not enough to model causation, that at base some kind of counterfactual statement is needed. Even Talmy is not immune to this worry, proposing (Talmy 2000, vol. 1: 491) a 'causative criterion' which is counterfactual in nature; with his force dynamics he does not need such a criterion. If forces are understood to arise from situations (Copley and Harley 2015), then merely by varying the size and content of the initial situation under consideration by the speaker, different forces can be brought to bear that result in different outcomes.

In this way, the tools to represent counterfactuality do not reside solely in the linguistic system with propositions true in possible worlds, but rather reside (instead or also) in our knowledge of the world, particularly in our mental simulations of what happens if certain forces are brought to bear. Mental simulation is an important part of our ability to consider what will or may happen next (Gilbert and Wilson 2007, Suddendorf and Corballis 2007), and as we saw above, there is indeed evidence from psychology that our knowledge of the world does include knowledge of forces, quite apart from linguistic competence. Such knowledge can be built into the semantic ontology in the definition of forces.

That said, production theories such as force-dynamic theories do not easily account for all linguistic phenomena. Causal connectives, for instance, are

apparently insensitive to intermediate causes, as in (9), nor do they easily distinguish between *cause* and *help*, as in (10) (Copley and Wolff 2014: 55).

(9) The door opened because of Tate.

(10) a. Lance Armstrong won seven Tours de France because of drugs.
b. ≠ Drugs caused Lance Armstrong to win seven Tours de France.

Since these distinctions are necessarily made in a force-dynamic theory, it looks as though force dynamics may not be the correct way to model *because*, contra Talmy.

Independently, a number of philosophers have come to the conclusion that more than one kind of theory of causation may be needed ('causal pluralism;' Hall 2004, Cartwright 2004, Godfrey-Smith 2010). Copley and Wolff (2014) have hypothesized that the difference between the two kinds of theories may be related to where in phrasal structure we are looking: force dynamics is relevant lower in phrase structure, while dependency theories, which deal in propositions, are relevant higher in phrase structure ('structural causal pluralism').

There is some evidence (Copley *et al.* 2015) that, contrary to the structural causal pluralism hypothesis, force dynamics is relevant everywhere in structure. However, if something like the structural causal pluralism hypothesis should turn out to be correct, it would also suggest that modality outside the verb phrase and modality inside the verb phrase should not be analysed in exactly the same way. Even if possibilities within the verb phrase are constructed by means of a force-dynamic theory (i.e., deriving possible worlds in terms of a force-dynamic understanding of causation) possible worlds at the higher level could still be atomic.

4.5 Formal force-dynamic theories

We now turn to the discussion of formal theories of force dynamics that have recently been proposed. Two categorical divisions stand out: first, a division between theories mostly concerned with how force vectors interact in space with entities, and which are therefore rather direct descendents of Talmy's work; and theories mostly concerned with the fact that the result of a force only obtains if nothing stronger intervenes *ceteris paribus*—'all else being equal'. Second, there is a division between, on the one hand, one theory (van Lambalgen and Hamm 2005), whose primary goal is to logically derive all and only the events that would occur, *ceteris paribus*, given certain starting conditions and

	data	force arguments	event arguments	categories
Zwarts (2010), Goldschmidt and Zwarts (2016)	force verbs and prepositions	are vectors (Zwarts and Winter 2000)	are associated with paths along which forces are exerted in time	syntax–semantics interface, vector-oriented
Pross and Roßdeutscher (2015)	conative alternation, other force verbs and prepositions	are atomic, introduced by force head within PP	are atomic, introduced by *v* head, interpreted as exertions of forces	syntax–semantics interface, vector-oriented
van Lambalgen and Hamm (2005)	event structure, viewpoint aspect	are functions from times to truth values ('fluents'), but the *Trajectory* predicate is closer to a force vector	are atomic; eventualities are ordered quadruples that include events and fluents	calculus that derives only and all the occurring events given starting conditions, *ceteris paribus*-oriented
Copley and Harley (2015, 2018)	event structure, viewpoint aspect	are functions from situations to situations	are replaced by force or situation arguments	syntax–semantics interface, *ceteris paribus*-oriented

TABLE 4.1 Formal force-dynamic theories

assumptions; and on the other hand, the other theories whose primary goal is to elucidate the syntax–semantics interface.

In Table 4.1 are shown the data each theory concentrates on, how force and event arguments are treated, and the categories the theory falls under.

4.5.1 *Zwarts (2010) and Goldschmidt and Zwarts (2016)*

Recent work by Zwarts and Goldschmidt (Goldschmidt and Zwarts 2016) uses vector representations of forces to understand verbs that seem to explicitly make reference to the application of force, such as *schlagen* 'hit' and *ziehen* 'pull', as well as these verbs' selection of certain prepositions. This project has its roots in Zwarts (2010) which made the initial connection to Wolff's vector theory of force dynamics for such verbs and prepositions (through Wolff and Zettergren 2002), and uses a formal model for vectors given in Zwarts and Winter (2000).

In Zwarts (2010), the case is made that force dynamics is indispensable for many prepositions[8] and verbs. For example, as a number of authors point out (Vandeloise 1991, Garrod *et al.* 1999, Coventry and Garrod 2004, Zwarts 2010, Gärdenfors 2014, a.o.), the preposition *on* cannot simply be understood as referring to a certain geometric configuration in which one object is located higher than another and in contact with it. Rather, the lower object must be supporting the higher object. Support can only be described using force-dynamic terms: not only is one entity above and in contact with another, but also the weight force associated with the first entity is opposed to an equal force by the second entity.

Likewise, the Dutch prepositions *op* and *aan* in Dutch, both glossed as 'on' in English, are distinguished respectively by relations of support versus attachment/hanging (Bowerman and Choi 2001, Beliën 2002). Notably, *op* is also used in cases of adhesion, which Zwarts argues to have the same abstract force-dynamic configuration as support. The only difference is that the force associated with the subject is not a gravitational force.

In addition to prepositions, Zwarts provides some examples of verbal predicates ('force verbs') that require a force-dynamic interpretation; he notes that the difference between *push* and *pull* does not correspond to direction of motion, since an agent can push and pull an object without it actually moving, but rather to direction of force, away or toward the agent. Rather, the difference between *push* and *pull*, as well as that between *squeeze* and *stretch* and between *lean* and *hang*, is one of the direction of the application of the force. So, any decomposition of these verbs must make reference to the direction of application of force in order to distinguish each pair of verbs. This direction of the application of the force, he notes, is distinct from the directions of the arrows in Talmy's force diagrams, since, for example, an agent can pull a patient toward themselves, while in Talmy's diagram such an example would be notated with an arrow from the agent (Agonist) toward the patient (Antagonist).

Finally, Zwarts notes that the prepositional and verbal meanings compose together in combinations that are expected from their force-dynamic meanigns, as in (11a,b):

(11) a. The lamp was attached to the ceiling.
b. The lamp was hanging from the ceiling.

[8] This point extends to the syntax of prepositions: Roy and Svenonius (2009) use Talmian force dynamics to account for meanings of causal prepositions such as *in spite of*, linking them to a general account of the syntax–semantics interface for prepositions. Case can also have meanings similar to prepositions, and accordingly Svenonius (2012*a*) links the North Sámi illative case to force dynamics.

As these predicates involve no motion or change along a path, the only plausible reason why *to* is selected in (11a) but *from* is selected in (11b) is that the lamp is associated with a force directed towards the ceiling in (11a), but in the opposite direction from the ceiling in (11b).

A fully compositional analysis of force verbs and prepositions is given in Goldschmidt and Zwarts (2016). The main contrast to be explained is in (12) (German):

(12) a. *Maria schlägt auf den Nagel.*
Maria hits on the nail
'Maria hits the nail.'
b. *Maria schlägt den Nagel in die Wand.*
Maria hits the nail in the wall
'Maria hits the nail into the wall.'

As part of a critique of a standard (neo-)Davidsonian approach to the contrast in (12), Goldschmidt and Zwarts point out that such an approach, without further elaboration, would incorrectly predict there to be no entailment relation between (12a) and (12b) while in reality (12b) entails (12a). They propose to solve this and other problems with the event-theoretic account of (12) by adding forces to the ontology.

For Goldschmidt and Zwarts, events have paths along which forces are exerted. This is achieved by having the origin of a force vector (perhaps with zero magnitude) at each moment of time along the path. Hitting, for instance, specifies a path along the surface of a patient with a punctual (one moment in the path) force applied on the path. Verbs describe sets of events while prepositions and adverbs describe sets of paths; this treatment of the syntax–semantics interface gives rise however to some compositional complexity, which they address by proposing two type-shifting operations.

The meaning of the sentence in (12a), according to Goldschmidt and Zwarts, is thus that there is a hitting event of which Maria is an agent, which has a path on which a punctual force is exerted on the surface of the nail. The sentence in (12b) ends up with the meaning that there is a hitting event of which Maria is an agent and the nail is a patient, and this event causes an event of the nail going into the wall (with a Talmian definition of causation involving the configuration of forces as in (2a)). Now (12b) does entail (12a), to the extent that a patient of a hitting event (in (12b)) is indeed hit on its surface, as is also true in (12a).

4.5.2 *Pross and Roßdeutscher (2015)*

In a 2015 presentation, Pross and Roßdeutscher also allude to Zwarts and Winter's (2000) vector semantics to explain, among other force verb–preposition combinations, the conative alternation as shown in (13) (German), which has an obvious parallel to the case discussed by Goldschmidt and Zwarts above in (12):

(13) a. *Peter zieht an der Rübe.*
Peter pull at the carrot
'Peter pulls at the carrot.'
b. *Peter zieht die Rübe aus der Erde.*
Peter pull the carrot out the soil
'Peter pulls the carrot out of the soil.'

Pross and Roßdeutscher's ontology is heavily informed by their theory of the syntax–semantics interface. For them, a parallelism between Kratzer's (1996) split VP and Svenonius's (2004) split PP gives rise to the idea of a forceP which plays the same role that a *v*P plays in verb phrases. The forceP is a predicate of forces while the *v*P is a predicate of events. To connect events to forces, in a marked departure from Talmy, events are considered 'exertions' of forces. The word 'exertion' here should probably be read simply as a notation of the idea that the event is the conduit through which the agent or initiator (Ramchand 2008*b*) of the event is connected to the force. A force has a region in space to which it 'attaches' (i.e., a point corresponding to the origin of the vector) and a region to which it is directed, as a 'goal'.

Their analysis of (13b) is that Peter is the initiator of an event which is an exertion of a pulling force, where the carrot is the force recipient (due to a small clause structure containing the carrot and the force-predicate preposition), and the goal of the pulling force is a region located out of the soil.

Note that we need an entailment that the carrot ends up out of the soil. For Pross and Roßdeutscher, this is part of what it means to be a force recipient, so that the fact that the carrot is the force recipient entails that it moves out of the soil. In contrast with (13b), (13a) for Pross and Roßdeutscher has no force recipient; the internal argument of *v*P supplies not a patient but a predicate of forces that attach (have their origin) on the carrot. Here again their assumption that force recipients undergo change is useful, as although the force has its origin on the carrot, the carrot is not considered a force recipient, and therefore is not assumed to move.

This notion of 'force recipient' in which the entity has to undergo change is an enormous departure from the usual idea of force recipient, in which all that is required is that the entity literally receive the input of energy; there is normally no requirement of change. Yet the idea that the grammatical patient in (13b)

undergoes change, but the argument of the preposition in (13a) does not, is obviously crucial to the explanation of the contrast in (13).

One way out of this is of course to change the role of the patient from 'force recipient' to something else that involves change. If on the other hand we do not wish to do this, given that not all grammatical patients undergo change, we would need an extra causal element, through a Talmian causal element as Goldschmidt and Zwarts propose (though this is what the grammatical configuration is meant to explain), or a closed-world assumption where *ceteris paribus*, which does similar work to the Talmian CAUSE configuration (about which more later in the sections on *ceteris paribus*-oriented theories, Sections 4.5.3 and 4.5.4 below).

To sum up the two vector-oriented theories we have seen, we can consider some similarities between them: not only do both use vector semantics and attention to spatial detail, but both theories use events for verb phrases, to which the agent/initiator is related, and forces for prepositions. The theories differ, however, in how the event is related to the force: for Goldschmidt and Zwarts, events have paths over which forces are exerted through time, and for Pross and Roßdeutscher, events are 'exertions' of forces. They also differ in their treatment of the syntax–semantics interface, with Goldschmidt and Zwarts proposing two type-shifting operations, as against the functional projection parallelism proposed by Pross and Roßdeutscher.

4.5.3 *Van Lambalgen and Hamm (2005)*

We move now from the vector-oriented theories to the *ceteris paribus*-oriented theories. While the former are concerned with force verbs and prepositions, the latter make a claim to being comprehensive theories of event structure, Aktionsart, and viewpoint aspect, especially progressive aspect, through an implementation of the *ceteris paribus* property, the fact that results only obtain if all else is equal. The first theory to have gone down this road is that of van Lambalgen and Hamm (2005), a powerful and general treatment of event semantics which crucially includes a representation of forces as a component of some kinds of eventualities.

This work does not build on the cognitive linguistic tradition of force dynamics with its emphasis on vector summation and force interaction—Talmy is never cited, for instance—but rather represents a development of the event calculus in artificial intelligence. The goal of van Lambalgen and Hamm (2005) is to understand the cognitive underpinnings of tense, Aktionsart, and viewpoint aspect, by constructing a computational theory of planning. A major claim of the work is that time is not basic to human thought but arises from the need to plan actions in the service of our goals. Taking this claim seriously, they propose that

the meaning of a natural language expression is an algorithm. While we cannot go into formal details of this proposal here, we can look at the broad lines that are relevant to forces.

Van Lambalgen and Hamm's core observation about planning is that we cannot foresee what will happen, but can only formulate a plan to the best of our knowledge to achieve our goal. We might echo Burns' words here: 'the best laid schemes o' Mice an' Men, / Gang aft agley'. Yet, we still can reason about plans by reasoning about what things will cause other things to happen, as far as we can figure. Accordingly, any such reasoning should be non-monotonic; conclusions can be defeated if unforeseen events arise—if *ceteris* are not *paribus*.[9]

To build in this *ceteris paribus* property, van Lambalgen and Hamm write the conclusions that reflect what happens next in the world given a certain state or event, but they take a closed-world assumption in which anything not mentioned is assumed not to hold. If something unexpected should happen, it must be added. In this way they can model what happens next, *ceteris paribus*, given the occurrence of a either a state or an event.

For states, they formulate a 'commonsense principle of inertia' in which 'a property persists by default unless it is changed by an event' (van Lambalgen and Hamm 2005: 42). In their model this principle is given in an axiom (their Axiom 3). This kind of inertia, which also is discussed in Comrie (1976) and Copley and Harley (2014), we might think of as 'no pain no gain' inertia: no pain (effort) results in no gain (no change).

For non-stative cases, they bring up results of force fluents through the expression $\mathit{Trajectory}(f_1, t, f_2, d)$, where f_1 is a force fluent, f_2 is a fluent representing a property that changes under the influence of the force, t is a time, and d is a duration. $\mathit{Trajectory}(f_1, t, f_2, d)$ expresses that if f_1 holds from time t until $t+d$, then f_2 holds at time $t+d$. Their Axiom 4 expresses that in such a case, f_2 is the default result of f_1—that is, if nothing intervenes, f_2 happens.

If one is used to representing forces with vectors, it is fair to ask whether this theory really utilizes force dynamics, since van Lambalgen and Hamm represent forces by time-dependent properties rather than by vectors; moreover, their forces do not interact with each other, but only through the intermediaries of events. And indeed something like a vector theory of forces would seem to be needed in addition to this theory. van Lambalgen and Hamm suggest that when they use the broad causal word 'affect,' in a paraphrase, they are referring

[9] This line of thinking about reasoning should remind us of dynamic semantics as in Section 4.3.2, though van Lambalgen and Hamm are talking about events rather than propositions.

informally to 'a kind of causal web which specifies the influences of actions on properties' (van Lambalgen and Hamm 2005: 42). It is exactly this causal web which can be represented in a vector model, but van Lambalgen and Hamm do not make note of this.

Still, van Lambalgen and Hamm's theory has a number of properties that place it squarely in the realm of forces. The *ceteris paribus* property which is central to their theory is crucial to the understanding of force and the absence of force. Michotte's two temporal relations for causation are modelled (launching with events that initiate and terminate fluents, and entrainment with *Trajectory*). They moreover stress that causation is a matter of events (which, again, for them sometimes include forces) not propositions (van Lambalgen and Hamm 2005: 43); recall the viability of this move made above in Section 4.4.3. To make an additional bridge between vector-oriented theories and van Lambalgen and Hamm's theory, we can understand van Lambalgen and Hamm's *Trajectory* as a kind of abstract or 'bleached' vector, with neither magnitude nor origin represented, but which represents direction in an abstract space of fluents. So there is still a measure of continuity between this and the vector-oriented theories.

This theory clearly gets a lot right. Yet it is difficult to reconcile van Lambalgen and Hamm's ontology with analyses of the syntax–semantics interface. In their ontology there are variables for (punctual) events alongside variables for fluents (time-dependent properties, including forces and states), and these participate in eventualities, which are themselves quadruples of three fluents and an event. Bittner (2006) and Copley and Harley (2015) argue that this ontology does not reflect the basic ontological difference between dynamic and stative verbal predicates that is cross-linguistically relevant to syntax. For example, as Bittner notes, the distinction between nouns and verbs is elided entirely. Another issue is that their basic typological division is one of temporal duration: there is an *event* type which does not have duration, and a *fluent* type which does, and fluents include both forces and (stative) properties. Consequently, there is no clear typological division between dynamic predicates (which involve either events or fluents or both) and stative predicates (which would involve fluents).

There are also some odd consequences of having fluents as a general time-dependent property. Commonsense inertia holds of fluents, which includes states and forces, so they have to 'turn it off' for forces with an axiom. This ontology also means they have to say that anything that decays naturally is not a state to them; so, for example, if sadness ultimately goes away on its own, *be sad* is not a stative predicate.

It is not that the theory is completely insensible to natural language syntax; for example, van Lambalgen and Hamm relate their event types and fluents to different kinds of nominalizations. However, as much as their use of algorithms

as meanings of expressions, these ontological issues have arguably also contributed to preventing the more widespread uptake of their framework in the syntactic parts of the field.

4.5.4 *Copley and Harley (2015, 2018)*

Copley and Harley (2015), like van Lambalgen and Hamm (2005), is a *ceteris paribus*-oriented theory, concerned with the whole of event structure, Aktionsart, and some aspect. Unlike van Lambalgen and Hamm (2005), it is primarily focused on how to use commonsense ideas about forces to explicate and streamline the syntax–semantics interface, reifying energy with force functions. Here I outline the main points of Copley and Harley (2015) and a follow-up article (Copley and Harley 2018) that reifies change by adding degrees to the ontology.

Copley and Harley begin by looking at cases of non-culmination of accomplishments with the so-called imperfective paradox (Dowty 1977, 1979) in (14) and non-culminating accomplishments as shown in (15) (see also Mittwoch's and Travis's chapters, among others, this volume):

(14) a. #Mary painted the dresser black, but she didn't finish.
b. Mary was painting the dresser black, but she didn't finish.

(15) *Inalis ko ang mantas, pero naubusan ako kaagad*
N-PF-remove GEN-I NOM stain, but run-out-of NOM-I rapidly
ng sabon, kaya hindi ko naalis.
GEN soap hence not GEN-I A-PF-remove
'I tried to remove (lit. 'I removed') the stain, but I ran out of soap, and couldn't.' (Dell 1983: 186)

There is clearly a sense of *ceteris paribus* in both (14b) and (15), to the effect that the agent is involved in doing something that would normally cause the result, if nothing happens to perturb it. If causation is really involved in these cases, it follows that it is possible to have a causal relation without the result obtaining, contrary to e.g. Lewis (1977), where causation entails that the result happens. Since Dowty's (1977, 1979) treatment of the progressive, one way to account for this issue is to call upon possible worlds, that the result obtains only in certain normal worlds and not necessarily the actual world. But this adds the complication of possible worlds. Another way to get out of trouble is to deny that there is a causal relation at all, and instead to call upon some non-causal notion of maximal events and partial events (e.g., Parsons 1990), but this raises the question of how to relate maximal to partial events, if not by causation.

A third way, which Copley and Harley pursue, is to use a theory of causation in which the result is not necessarily entailed. They propose that the Davidsonian argument refers to an action that *ceteris paribus* causes the result, with the understanding that things may not be equal, as something external may intervene. This notion, they note, corresponds to the commonsense notion of force.[10] But it is important to define the notion of force-dynamic causation in order for this move to work. In fact, though Copley and Harley do not note it, the Talmian CAUSE configuration (see (2a) above) is result-entailing: the Agonist (agent) force must overcome the Antagonist's force. So it cannot be used in these cases.

4.5.4.1 **A force-theoretic framework** The technology that Copley and Harley propose to account for non-culmination has several components, based on the specifications that the idea provides.

A first specification is the *ceteris paribus* property: the occurrence of the result of a force should be defeasible. For this, Copley and Harley use the closed-world assumption that van Lambalgen and Hamm also use; anything not mentioned that is not normally assumed is assumed not to be the case. The closed-world assumption takes on a special importance as Copley and Harley consider how forces arise. A situation σ in the world (as in situation semantics, Barwise and Perry 1983) can include various entities and their properties. Copley and Harley add the idea that a force φ arises from a situation σ, and in particular, from the entities and their properties. So to take a closed-world assumption is to assume that no forces intervene that arise, totally or partially, from outside the situation one is considering with its particular entities and properties and general laws of nature and rational behaviour. When the closed-world assumption is made, the result of the force occurs (Copley and Harley call this 'efficacy'), so if there is morphology that is associated with culmination, its meaning boils down to the closed-world assumption.

Second, a consequence of having defeasible results in this way is that we need to make reference to the result without having to assert its occurrence (existence). How is this to be done? Given that a force takes us, *ceteris paribus*, from one situation to another as in the case of pushing a cup from one edge of the table to the other, Copley and Harley propose to represent a force with a function with a single situation in its domain s_0 and a single situation in its range s_1, such that $f(s_0) = s_1$. In this way, the Davidsonian argument *is* the causal element, as in production theories of causation, and no extra CAUSE relation is needed. Copley

[10] An earlier instance of force dynamics for progressives is in Bohnemeyer and Swift (2006); only for certain verbs, however, and in addition to the use of events.

and Harley's force functions are effectively a way to incorporate information about causation into the ontology.

A third specification is that a tension between the first and second specifications must be resolved: a force arises from a situation, but it also acts on that very same situation, *ceteris paribus*, to cause the next situation. So how can the force have these two different relations to the situation? The resolution of this tension lies in the adoption of a dual ontology along the lines of Barwise and Perry (1983), where the conceptual entities are different from, but mapped to, the formal entities. In addition to this suggestion, it has also been independently suggested (Borer 2005*a*, Glanzberg 2011, Roy and Soare 2013) that an analogue conceptual ontology and a digital logical ontology both exist as distinct levels of meaning, and that the mapping between them is not necessarily identity. An analogy could also be made to the relationship between number sense and counting: a single domain in which there is a 'fuzzy' concept as well as a related formal, generative system.

This is a familiar point; 'No function is a color, a smell, a shape, or a feeling' Bealer (1989: 1). This is always the case where there is an evaluation function that maps, e.g., formal predicates to conceptual properties, but normally the evaluation function does not apply to entities, even though, for example, one would think predicates must apply to a different type of object than properties do in order that predicates and properties can differ. In any case Copley and Harley propose to use the evaluation function for entities as well. This allows two different force–situation relationships, one on the conceptual level and one on the linguistic level.

On the conceptual level, conceptual forces arise from conceptual situations (like Barwise and Perry's 'real' situations) as in (16a). Force functions and linguistic situations (like Barwise and Perry's 'abstract' situations) are mapped to conceptual forces and conceptual situations respectively by the evaluation function, as in (16). A force function takes a linguistic situation (related by the evaluation function to the conceptual situation from which the conceptual correlate of the force function arises) and returns a different linguistic situation, as in (16). We can also speak of f as being the net force of s_0.

(16) Let φ arise from all the entities and properties in σ and let $[\![f]\!] = \varphi$ and $[\![s_0]\!] = \sigma$. Then:
   a. $net(s_0) =: f$
   b. $f(s_0) =: s_1$, where $[\![s_1]\!]$ =the situation σ' which results from φ *ceteris paribus*

Like van Lambalgen and Hamm's *Trajectory* predicate, Copley and Harley's force function is a bleached vector, because a force function f has an abstract

direction, namely s_1. Unlike *Trajectory*, Copley and Harley's force function also an abstract origin, namely s_0. Magnitude is still not represented.

Additional functions to relate arguments to each other are also defined, such as in (17):

(17) Where $f(s_0) = s_1$:
a. $\mathit{init}(f) =: s_0$
b. $\mathit{fin}(f) =: s_1$

One might wonder where the events are in this theory. The role of the 'container' for forces, played by events in cognitive linguistic theories, is here played by situations. Copley and Harley (2015) decline to use the word 'event' for anything but change, and take the radical position that Davidson was entirely wrong about what his arguments corresponded to: not commonsense events (changes), but commonsense forces (inputs of energy). They propose instead that the Davidsonian arguments that dynamic predicates are predicates of are forces, while those that stative predicates are predicates of are situations. Change is represented in the difference between one situation and the next, but is not reified in any argument. However, Copley and Harley (2018) add degree arguments to this system to reify change (Section 4.5.4.4 below).

4.5.4.2 **Accounting for non-culmination** For non-culminating accomplishments, the proposal is simply that the closed-world assumption (which results in 'efficacy') is not made. For the progressive, a denotation is proposed that takes a predicate of forces π and a situation s, and says simply that the predicate of forces holds of the net force of the situation:

(18) $[\![\text{progressive}]\!] = \lambda\pi\lambda s.\pi(\mathit{net}(s))$

The complexity of the progressive is thus in the conceptual system, which evaluates what the *ceteris paribus* result is as in (16b), not in the logical form. This greatly simplifies the logical form.[11]

[11] A side-effect of this analysis is that Talmy's contrast in (1) between a mere progressive and a progressive with *keep* is no longer about the existence of force, as both sentences now involve force. Rather, it is about the contribution of *keep p* as providing a force where *p* is true in both the initial and final situation. The sense of opposition that Talmy foregrounds in his analysis would then be an epiphenomenon of the notion that a force is necessary for the situation (the one in which the ball is rolling) to be maintained, so there must be some other force opposing it.

Force functions are useful for other aspects besides the progressive. For one, they allow for causally-linked chains of situations. This fact makes force functions particularly appropriate for resultative aspect. For example, a simpler version of Ogihara's (1998) analysis of Japanese *-te iru* as sometimes progressive, sometimes resultative, becomes possible. In subsequent work, Błaszczak and Klimek-Jankowska (2012) use force functions to address aspectual distinctions in future reference in Polish. The use of forces furthermore illuminates the denotations of aspect in interaction with other force-dynamic meanings, as in Giannakidou and Staraki (2013) and Copley and Harley (2014).

4.5.4.3 **A viable syntax–semantics interface** Force functions further allow Copley and Harley to retain and improve on existing syntax–semantics interfaces for dynamic verb classes. They propose flavours of the verbalizing causal head *v* (Folli and Harley 2005) as in (19): v_{become} for changes of state, v_{appear} for verbs of creation, v_{emerge} for denominal verbs of birthing and the *sweat*, *bleed* class (Harley 2005), v_{occur} for activities (atelic dynamic predicates), and v_{stay} for verbs of maintaining as discussed above in Section 4.1.2. In English all of these also have a presupposition of efficacy; furthermore, (19a)–(19d) have a presupposition that p does not hold of $init(f)$, while in (19)e there is a presupposition that p holds of $init(f)$. The type for situations is s, and the type f abbreviates the type ss for forces.

(19) a. $[\![v_{become}]\!] = \lambda p_{st} \lambda f.p(fin(f))$
b. $[\![v_{appear}]\!] = \lambda x \lambda f.x < fin(f)$
c. $[\![v_{emerge}]\!] = \lambda p_{st} \lambda f.[\exists y < fin(f) : p(y)]$
d. $[\![v_{occur}]\!] = \lambda \pi_{ft} \lambda f.[\exists f' < fin(f) : \pi(f')]$
e. $[\![v_{stay}]\!] = \lambda p_{st} \lambda f.p(fin(f))$

The general idea in all of these is that a force described by the verb root has a *ceteris paribus* effect (the situation fin(f)) which has a certain property, or which includes an entity with a certain property. One benefit of this approach is that it allows a causal relation between the subparts of an accomplishment without calling on the main verb *cause*, a decompositional paraphrase which some speakers view as problematic for e.g. verbs of motion. That is, if Mary walks to the store, it need not be true that Mary's walking causes her to be at the store; it need only be true that her input of energy (in the walking manner) has as a result that she is at the store.

Another welcome consequence of this approach is that temporal variables are not needed in verbal semantics, following Talmy and Gärdenfors, but contra Croft.[12] Instead, everything is causal.

Perhaps the most surprising case is that of v_{occur}, which is Copley and Harley's flavour of *v* for activities; it is surprising because atelic predicates, unlike telic predicates, do not normally have a causal analysis. As we have seen in the force-dynamic approaches, there are two possible temporal relationships for causation: launching and entrainment. However, event semantics at the interface with syntax has to date focused exclusively on launching causation (e.g. Pustejovsky 1995, Higginbotham 2000*a*, Ramchand 2008*b*), in part probably because entrainment would raise a problem regarding event individuation for Davidsonian events. Copley and Harley understand telic predicates as cases of launching, much as the rest of the literature does. The new part is that they are now able to understand atelic eventive predicates as cases of entrainment, where the result happens at the same time as the application of the force. That is, if you dance, or heat the soup a little bit, the result of the input of energy happens (there is some dance, or the soup is hot to some degree) at the same time you are putting the energy in; while if you dance to the door, or heat the soup to boiling, the result (you are at the door, the soup is boiling) happens after you are done putting the energy in. This observation allows Copley and Harley to analyse even atelic dynamic predicates with a simple causal analysis as in (19d). The observation that telicity is not represented in the verb (e.g., Filip 2008) is then a consequence of the idea that temporal relations are not represented in the verb, only a causal relation, where the cause and result can have either of Michotte's two temporal relations.

To add the agent to the *v*P, Copley and Harley follow Kratzer (1996) and many others in proposing a Voice head, which for them introduces the source of the force's energy. Thus there is no syntactic distinction made between animate agents and inanimate causers. Their treatment provides a way to account for what Ramchand (2008*b*, this volume) calls 'causal semantic glue' with only the theta role *Source* and Functional Application, in effect moving the causal 'glue' to the ontology. Similarly, Kratzer's Event Identification compositional rule, which links subevents, is also not needed because the force and its result are already linked in the ontology.

[12] And the exact opposite of the approach taken by Verkuyl (this volume), though the spirit of harmonizing Aktionsart and aspect is similar. The absence of temporal variables is consistent with the idea (see Gehrke, this volume, and references therein) that within the verb phrase Davidsonian arguments are not located in time.

4.5.4.4 **Adding degrees to reify change** Copley and Harley (2015) streamlines the syntax–semantics interface of several major types of verbal predicates. A notable omission, however, is that with the emphasis on using Davidsonian arguments to reify energy, change is not reified at all but is only expressed by a change from $\neg p$ to p. This is an oversimplification which leaves out predicates that express change of degree along a graded scale (Hay *et al.* 1999, e.g.; and see Mittwoch's and Ramchand's chapters, this volume). This omission can be addressed by adding degree arguments to the framework of Copley and Harley (2015) and explicitly linking the degree-based understanding of (a)telicity to the contrast between launching and entrainment (Copley and Harley 2018). When a maximum value on a degree scale must be reached in order for the predicate to be true (telicity), this maximum value is reached at the end of the application of force (launching). On the other hand, when only a minimum value on a degree scale need be reached for the predicate to be true (atelicity), this value is reached immediately when the force is applied (entrainment). The hypothesis explored by Copley and Harley (2018) is that the resulting system yields a uniform verbal meaning. This meaning would introduce a force that provokes a (possibly zero) change in the degree to which a property holds on a scale as shown in (20), where p_{sd} denotes a predicate of type $\langle \text{sd} \rangle$, and a degree-interval is analogous to a temporal interval. On this hypothesis, the Copley and Harley (2015) flavours of v in (19) are each a special case of the general version in (21), with the differences between them constructed in the syntax.

(20) Measure of impelled change:
$\Delta(p_{sd})(f) =$:the degree-interval spanning the degree to which p holds of $(init(f))$ and the degree to which p holds of $(fin(f))$, inclusive.

(21) Unified v (replaces all flavours in (19)):
$[\![v]\!] = \lambda p_{sd} \lambda f . \Delta(p)(f)$

In addition to reflecting closely the event-theoretic proposal in Hay *et al.* (1999), this hypothesis is reminiscent of Koenig and Chief's (2007) proposal for non-culminating accomplishments, and is also not far from Gärdenfors and colleagues' cognitive linguistic perspective on verbal meaning (Warglien *et al.* 2012, Gärdenfors 2014), if scales are understood as conceptual spaces.

4.5.4.5 **Comparison to the other theories** We now turn to the question of how Copley and Harley's force-theoretic framework relates to the other formal force-dynamic theories discussed earlier.

Two significant commonalities between Copley and Harley's and van Lambalgen and Hamm's theories are the treatment of the *ceteris paribus* property via a

bleached vector and the closed-world assumption, and the representation of both of Michotte's temporal relations. However, there are also important differences in how forces are treated. One difference is that for Copley and Harley the *ceteris paribus* property is built into definition of the force argument itself, so it is the force argument itself which is a bleached vector. For van Lambalgen and Hamm, by contrast, the force argument (fluent) is rather inert, and the *ceteris paribus* property comes from an additional predicate (*Trajectory*) in combination with an axiom. Another difference is that Copley and Harley's bleached vectors (force functions) include information about the origin as well as the direction while van Lambalgen and Hamm's bleached vector (*Trajectory*) has no information about the origin. Finally, Michotte's temporal relations line up with (a)telicity only for Copley and Harley, not for van Lambalgen and Hamm. These differences all militate in the direction of a simpler ontology as well as a simpler syntax–semantics interface for Copley and Harley.

The comparison between Copley and Harley's theory and the vector-oriented theories is intriguing. As a reminder, the vector-oriented theories deal with what 'force verbs'—those that literally involve an entity exerting a physical force on another entity—as well as prepositions such as *to*, *from*, and *against*, and the selection of certain prepositions by force verbs. These theories do not claim to be a comprehensive theory of event structure, Aktionsart, and (eventually) aspect, as Copley and Harley (2015) does. Yet, while some force verbs are mentioned explicitly by Copley and Harley (e.g. *push*), the idea of a force acting on an entity is not modelled at all by their force functions. Thus we must ask to what extent Copley and Harley's framework can account for the data treated by the vector-oriented theories.

Since Copley and Harley's force functions are bleached vectors that represent an origin (the initial situation in which the force arises) and a direction (the final situation that arises *ceteris paribus* from the application of the force), their theory should be able to account for the cases that make use of only these elements, provided the initial situation is truly understood as providing the spatial location of the application of the force. For example, the contrast that Goldschmidt and Zwarts and Pross and Roßdeutscher present in (12) and (13) above, between hitting on the nail/pulling on the carrot and hitting the nail into the wall/pulling the carrot out of the soil, can be analysed as in (22). For hitting on the nail, shown in (22a), the initial situation is located on the nail; for hitting the nail into the wall, [den Nagel in die Wand] is treated as a small clause[13] that holds of the final *ceteris paribus* situation of the force. *Ceteris* are assumed to be *paribus*, in German as in English, so $\mathrm{fin}(f)$ occurs.

[13] Goldschmidt and Zwarts declare themselves open to a small clause account, though they ultimately choose a different analysis.

(22) a. $\lambda f.\text{schlagen}(f)\&[\![\text{auf de Nagel}]\!](\text{init}(f))$
b. $\lambda f.\text{schlagen}(f)\&[\![\text{den Nagel in die Wand}]\!](\text{fin}(f))$

Thus, Copley and Harley's theory is sufficient for these cases.

On the other hand, there are facts that *prima facie* cannot be explained with Copley and Harley's theory because the analysis would call upon elements that their theory does not represent. The question is then whether a minimal extension of the theory *could* represent them. In one case, the case of relative magnitude in force interaction, essential for cases such as *prevent*, the answer is a qualified yes. While Copley and Harley do not really represent either magnitude or the interaction of two forces, Copley *et al.* (2015) extend a suggestion made in Copley and Harley (2015) about how to represent Antagonist forces as a force separate from the Agent's force by exploiting two ideas: first, that forces arise from situations, and second, that situations have a part structure. If the Agent's force is f, then one can speak of a different force f' which arises[14] from a proper part of the initial situation of f. In a language like English, the final situation of f occurs because of the closed-world / *ceteris paribus* assumption. Since the final situation of f occurs, that means that f was stronger than f'. It remains to be seen whether this mechanism could account for all cases of force interaction in addition to the verbs and causal connectives that are discussed by Copley *et al.* (2015), or whether the forces' interaction really needs to be represented in a more direct way, but it is a start.

On the other hand, magnitude outside of force interaction sometimes needs to be referred to directly, as Goldschmidt and Zwarts point out regarding the German adverb *hart* 'hard', which measures the intensity of the input of energy, and which is compatible with force verbs such as *schlagen* 'hit' but not with verbs such as *essen* 'eat'. This explanation cannot be replicated in Copley and Harley's theory, as for them all dynamic verbs involve force functions.

Another element that seems impossible to represent in Copley and Harley's theory is Zwarts' 'other direction' that characterizes, for example, the difference between *push* and *pull*, and the difference between *to* and *from*. The reason for this that the direction of Copley and Harley's bleached vector force function in a case like *pull* is toward a successful pulling on the patient, and nothing is said about what it means to pull. Likewise, the difference between *to* and *from*, as well as the selection of one or the other by force verbs, cannot be represented.

Such issues are all questions of choosing lexical items which go well with each other based on world knowledge. In contrast, grammatical distinctions such as

[14] Strictly speaking we should be talking about conceptual forces $[\![f]\!] = \varphi$ and $[\![f']\!] = \varphi'$ arising from conceptual situations, but I elide that here.

Aktionsart and aspect (in English and cross-linguistically at least to my knowledge) do not rely on magnitude or Zwarts' direction. Instead much of the grammatical side hinges on the *ceteris paribus* property, which is not dealt with at all by the vector-oriented theories.

This split can be resolved if we recall the grammatical/conceptual mapping discussed above in Section 4.5.4.1, and recall as well that the notion 'lexical' falls under the notion 'conceptual'. Copley and Harley (2015), as we have seen, suggest that forces correspond to functions in a linguistic, digital ontology. To make such a suggestion is to suggest that there is a mapping that is non-identity between forces in (our conceptual model of) the world—inputs of energy—and forces as represented in a digital linguistic ontology, since an input of energy is not a function. The evaluation function mediates between them: $[\![f]\!] = \varphi$. Such a distinction between grammatical and conceptual forces has also been suggested by experimental results on causal expressions in Copley *et al.* (2015), where a conceptual force individuation criterion is proposed to require that two conceptual forces with the same origin be vector added together to form a single force; however, two *grammatical* forces with the same origin can be compared.

So, if there are both grammatical and conceptual forces, this gives us the option of attributing different characteristics to a grammatical force f and a conceptual force φ. Perhaps our conceptual model of φ is a detailed vector representation. And perhaps some characteristics of force vectors are relevant at the lexical–conceptual level, but only a subset of those are relevant at the grammatical level, and those that are are realized in a more abstract way. This could effectively relieve the tension between a view of forces as affecting entities, as in Talmy's work and the vector-oriented approaches, versus forces as applied to events or situations, as in Croft's relations between events and the *ceteris paribus*-oriented theories. Both kinds of theories could then be used, each at the appropriate level.

4.6 Conclusion

To conclude, there are a number of benefits to semantic theory that are not easily available unless force dynamics is taken into consideration. While it may seem at first glance that a force-based perspective is incompatible with formal ontologies based on reified events and possible worlds, this is by no means the case. Investigation into the integration of force dynamics with formal semantics has the potential to simplify the mapping between syntax and logical form clarify the mapping between a conceptual-level ontology and the linguistic level of ontology employed at logical form. In general, then, the force-dynamic turn

provides opportunities to further probe the interaction between syntax and semantics, and to hold semantics to a new standard of accuracy at the grammatical–conceptual interface.