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Massimo Warglien, Peter Gärdenfors and Matthijs Westera

Event structure, conceptual spaces and the semantics of verbs

Abstract: The aim of this paper is to integrate spatial cognition with lexical semantics. We develop cognitive models of actions and events based on *conceptual spaces* and vectors on them. The models are then used to present a semantic theory of verbs.

We propose a two-vector model of events including a force vector and a result vector. We argue that our framework provides a unified account for a multiplicity of linguistic phenomena related to verbs. Among other things it provides a cognitive explanation for the lexico-semantic constraint regarding manner vs. result and for polysemy caused by intentionality. It also generates a unified definition of aspect.

Keywords: actions, events, conceptual spaces, similarity, force vector, result vector, manner/result complementarity, aspect

Massimo Warglien: Università Ca' Foscari, Dipartimento di Management, Cannaregio 873, 30121 Venezia, Italy. E-mail: warglien@unive.it
Peter Gärdenfors: Lunds Universitet, Filosofiska institutionen, Kungshuset, Lundagård, 222 22 Lund, Sweden. E-mail: peter.gardenfors@lucs.lu.se
Matthijs Westera: Universiteit van Amsterdam, Faculteit der Geesteswetenschappen, ILLC, P.O. Box 94242, 1090 GE Amsterdam, The Netherlands. E-mail: m.westera@uva.nl

1 Introduction

Currently, linguistic research provides a rich characterization of the semantics of verbs (e.g. Levin and Rappaport Hovav 2005, Croft 2012). It is generally presumed that there is a close tie between cognitive representations of actions and events on the one hand and the semantics of verbs on the other. In linguistic research, the focus is on the role of verbs in different constructions, while in studies of action, the focus is rather on how actions are represented cognitively. However, a unifying framework connecting the semantics of verbs with such cognitive structures is still lacking.

Jackendoff (2002) has advocated a tighter integration between the spatial level of cognition and lexical semantics. The aim of this paper is to expand this integration by developing cognitive models of actions and events based on conceptual spaces and then use them to present a semantic theory of verbs. We attempt to bridge the research on actions in cognitive science (Giese and Poggio 2003, Giese et al. 2008, Hemeren 2008, Gärdenfors and Warglien, to appear) with work on verbs in lexical semantics.

In section 2, we expand upon the earlier analysis of concepts and properties – in terms of conceptual space – to actions and changes of properties. In section 3, we apply the expanded framework and propose a two-vector model of events. That model is then applied to present an analysis of the semantics of verbs in section 4. We argue that our framework provides a unified account of a multiplicity of linguistic phenomena related to verbs and a cognitive explanation for such puzzling properties as the lexical constraint regarding manner and result verbs. Finally, section 5 compares our theory with the localist, aspectual and causalist approaches (as classified by Levin and Rappaport Hovav 2005, ch. 4).

2 Conceptual spaces as a modelling tool for semantics

2.1 Properties and concepts

Conceptual spaces have been proposed as tools for modelling the semantic meanings of natural language expressions. Gärdenfors (2000) argues that properties can be represented by convex regions of dimensional spaces.[1] For example, the property of being red is represented by a convex region of the three-dimensional colour space. Convexity of representations seems to play a central role for cognition: Gärdenfors (2000) argues that convexity facilitates learning and Warglien and Gärdenfors (to appear) argue that convexity facilitates communication.

A concept – in the most general sense – can then be defined as a bundle of properties that also contains information about how the different properties are correlated.[2] For example, the concept of an apple has properties that correspond to regions of colour space, shape space, taste space, nutrition space, etc.[3] The distinction between properties and concepts is useful when analysing the cognitive role played by different word classes. Gärdenfors (2000) proposes that the meaning of an adjective is typically a property, described as a convex region of a

1 A set S is convex if and only if, for any x and y in S, every z that is *between* x and y is also in S.

2 See Gärdenfors (2000, p. 105) for a more precise definition.

3 See Gärdenfors (2000, pp. 102–103) for a more precise account of this example.

domain such as colour, shape or size. Correspondingly, the meaning of a noun is typically a concept represented as a complex of properties from a number of domains: that is, nouns typically denote bundles of properties.[4] A main aim of this paper is to extend this analysis to the semantics of verbs.

Since the notion of a domain is central to our analysis, we should give it a more precise characterization. In contrast to linguistic analyses, from Langacker (1987) on, we rely on the notions of separable and integral dimensions as taken from cognitive psychology (see e.g. Garner 1974, Maddox 1992, Melara 1992). Certain quality dimensions are integral in the sense that one cannot ascribe an object a value on one dimension without giving it a value on the other(s). For example, an object cannot be given a hue without also giving it a brightness. Likewise, the pitch of a sound always comes with a certain loudness. Dimensions that are not integral are said to be separable, e.g. the length and hue dimensions. Using this distinction, a domain can now be defined as a set of integral dimensions that are separable from all other dimensions.

The notion of a domain has been discussed in cognitive linguistics (e.g. Langacker 1987, Croft 1993, Evans and Green 2006 and Croft and Cruse 2004). Langacker's (1987, p. 5) notion of a basic domain fits well with the notion of domain presented here. Besides basic domains, Langacker talks about abstract domains, for which identifying the underlying dimensions is more difficult. In general though, it seems that the notion of a domain within cognitive linguistics has a broader meaning than the one intended here.[5] Croft and Cruse (2004, ch. 2) go as far as identifying domains with frames in the tradition of Fillmore (1976).

2.2 Representing change

What distinguishes verbs from adjectives and nouns is that they denote a change in properties, which we model as the movement of an object's representation through a conceptual space. For example, as an apple ripens, its representation moves from green to red in colour space and from sour to sweet in taste space.

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4 This is similar to the *domain matrix* proposed by Langacker (1987). Information about the meronymic structure of objects may also be part of a concept (see Gärdenfors and Löhndorf 2011).

5 Langacker (1987, pp. 152–154) distinguishes between "locational" and "configurational" domains, where locational means being located within dimensional space, while configurational concerns the relations between the parts of objects. The first notion fits well with the one proposed here. We view the second as a mereological concept of a different nature (see Gärdenfors and Löhndorf 2011).

Thus the representation of the object changes from one position (the start point) to another (the end point) within the underlying conceptual space. The pair of points (start, end) in the noun region can be viewed as a *vector* – consider it as an array of the initial and final snapshots of the object positions in that space. Such a vector represents a change of object's properties – and thus it introduces a form of kinematics.[6]

Conventionally, a vector has direction (the line on which it is lying), verse or sense (where its arrow points) and magnitude (the distance from start to end point). When needed, a change can be partially represented by its verse (e.g. up or down) and its magnitude (large or small).

In general, a change of state is not represented by a specific vector. Instead, it can be represented by a category of changes of state. Just like categories of objects are regions in a conceptual space, so categories of changes are regions in a space of result (or "displacement") vectors. If the start point is set as the origin, one can represent a category of change events as a region of end points. A natural generalization is that such regions should be convex regions in the space of end points. For example, going "upwards" in a two-dimensional space will correspond to a convex region of points located in a cone to the "north" of the origin.

A change event need not happen instantaneously. In general, it unfolds in continuous time. Cognitive semantics has widely exploited the notion of a *path* to express such continuous change of state. Topologically, a path is a connected set of points going from a start to an end point. Making the path explicit can be very useful when more than the direction and magnitude of change need to be represented. For example, to express the event of crossing a park, it is not enough to consider an entity's (e.g. Jane's) change of position between two points: say, two gates of the park. If Jane goes from one gate to the other one by going around the park, one cannot say she has crossed the park. Reasonably, "crossing the park" will be represented by a path connecting the entry gate to the exit one and lying entirely within the boundaries of the park itself. Indeed, in this case, rather than a specific path, a category of paths will do – most of the time. Once more, one expects such a category to be a "convex" set of paths. The notion for paths of betweenness, – and thus convexity – can be given a precise mathematical description. Here we will just rely on the intuitive notion of one curve lying between two others. It is quite likely that the path going as straight as possible from the entry gate to the exit will act as the prototype for such a category.

6 Sometimes – for obvious reasons of cognitive economy – one can take the start point as the "origin" in the spatial representation of the change. In that case, no explicit representation of the start point will be needed, and the change will be represented by just the end point.

Representing a path through all its points is a cognitively very expensive operation. This would make it hard to express it in language, which is made of discrete entities (words). However, a continuous path can be approximated well by a series of discrete changes of state: once more a chaining of vectors, or, if you wish, an array of snapshots including some intermediate point(s). Having an intermediate point between the start and end points might be enough to express that the path is, indeed, going through the park. Again, "betweenness" can be defined quite easily in terms of the approximated paths defined by the simplified vector representation.

With the aid of vectors representing the changes of state of objects, one can very naturally define three important notions:

i. A *state* is a point in a conceptual space[7]
ii. A *change* of state is represented by a (non-zero) vector in such space
iii. A *path* is a concatenation of changes of states.

In its original meaning, a path is a series of changes in the domain of physical space, but the meaning of "path" can naturally be extended to changes within other domains.

2.3 Representing actions

In Gärdenfors (2007) and Gärdenfors and Warglien (to appear), the analysis in terms of conceptual spaces has been extended to representing actions. When one perceives an action, one does not just see the movement, one also extracts the forces that control different kinds of motion. Runesson (1994, pp. 386–387) formulates this as the *principle of kinematic specification of dynamics*, which says that the kinematics of a movement contain sufficient information to identify the underlying dynamic force patterns. Our proposal is that, by adding forces, one obtains the basic tools for analysing the dynamic properties of actions. Once more, the language of vectors will be of great representational convenience. Of course, force vectors are different from change vectors: they do not represent changes of state but the causes of changes of states, a kind of higher-level change process. They are manifested by changes of velocity, direction or shape, but they enable one to maintain a dimensional representation.

7 A state can be seen more properly as the identity vector: that is, a vector going from a point to itself. A state *category*, such as "being warm", is represented by a region of a conceptual space (see Section 3.1 and Gärdenfors and Warglien, to appear).

For many actions – for example moving and lifting – a single force vector may be sufficient, but for others – such as walking and swimming – a complex of forces is involved. We therefore define an action as a *pattern of forces* since several force vectors are interacting (by analogy with Marr and Vaina's (1982) system of differential equations).

To identify the structure of the action space, one should investigate *similarities* between actions. This can be done with basically the same methods as for similarities between paths: e.g. *walking* is more similar to *running* than to *throwing*. An action concept can then, in the same way as with other concepts, be characterized as a convex region in a space of force vectors or force patterns.

Force vectors are central ingredients in our model of events. The three concepts of state, change and path already provide some other ingredients. In this way, events can be constructed naturally from the components of domains of conceptual spaces. As we shall show later, force space can also be extended metaphorically to represent psychosocial powers.

The components related to action, sketched in this section, lay the groundwork for the model of events that we shall now develop. We will apply this model to the analysis of the semantics of verbs in section 4.

3 A two-vector model of events

When describing events, one must importantly distinguish three different approaches:

i. *Metaphysical analyses* describing the ontology of events. One finds several such accounts in philosophy, in the works of Davidson (1967), Kim (1976), Casati and Varzi (2008), and others.
ii. *Cognitive models* of events that account for how humans (and perhaps other animals) represent events mentally. The model we propose is of this kind. We want to distinguish between (a) *mental models* of events, which contain representations of causes and effects; and (b) *construals*, which form the semantic basis for utterances. A construal is a mental model of an event with a particular focus of attention (i.e. topic) added to it (see e.g. Langacker 1987, section 3.3; Givón 2001; and Croft, 2012, section 1.4).
iii. Studies of *linguistic expressions* describing construals of events.

In linguistics, a tight mapping is often assumed between linguistic expressions and construals of events. Events are often modelled using symbolic notation

(Jackendoff 1990). For example, Rappaport Hovav and Levin (1998, p. 116) represent the meaning of the verb *break* as follows:

[[X $\text{ACT}_{\langle\text{MANNER}\rangle}$] CAUSE [Become [Y ⟨BROKEN⟩]]]

In this kind of analysis, one never really leaves the linguistic level (The verb *break* reappears as ⟨BROKEN⟩). As a consequence, the approaches (ii) and (iii) are sometimes not clearly separated. Croft (2012, pp. 33–34) complains about "the pervasive confusion in virtually all linguistic discourse between the use of a term for a conceptual category and the use of the same term for a language-specific grammatical category." In contrast, our model of events is constructed from vectorial representations in conceptual spaces. Thus, events are clearly separated from linguistic expressions.

3.1 The basic model

With the analysis of paths and actions as background, we can now put forward our model of events. Both paths and actions are fundamentally relational concepts that focus on mappings within conceptual spaces – represented as change and force vectors. We claim that event representations are characterized by the mapping between the two types of vectors.

We formulate this claim as a necessary requirement on event representation:

The two-vector condition: A representation of an event contains at least two vectors and at least one object – a *result* vector representing a change in properties of the object and a *force* vector that represents the cause of the change.

The structure of the event is determined by the mapping from force vector to result vector. We will call the central object of an event the *patient*.

A prototypical event is one in which the action of an agent generates a force vector that affects a patient causing changes in the state of the patient. As a simple example, consider the event of Oscar pulling a sledge to the top of the hill (see figure 1). In this example, the force vector of the pulling is generated by an agent (Oscar). The result vector is a change in the location of the patient – the sledge (and, perhaps, a change in some other of its properties, e.g. it is getting wet). The result depends on the properties of the patient along with other aspects of the surrounding world: in the depicted event, e.g. gravitation and friction act as *counterforces* to the force vector generated by Oscar. (These counterforces explain why the result vector is not parallel with the force vector.)

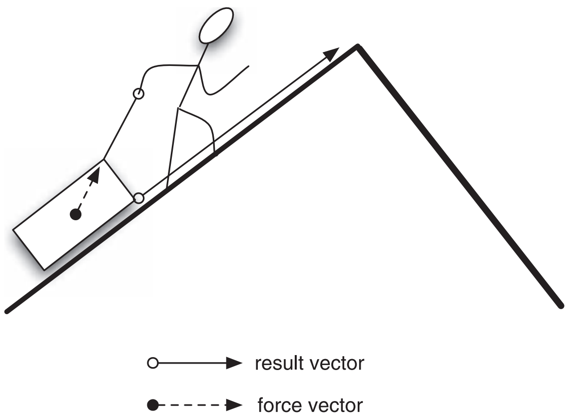

Fig. 1: The vectors involved in the event of Oscar pulling a sledge to the top of the hill.

Even though prototypical event representations contain an agent, there are event representations without agents, for example in events of falling, drowning, dying, growing and raining.

We can thus model causation by introducing a distinction between forces and changes of states. Our model of events can be seen as a version of Kant's idea that causation is one of the *Anschauungsformen* of human thinking. The vectorial representation of forces provides a natural spatialisation of causation that unifies our model with other applications of conceptual spaces. In the limiting case when the result vector is the identity vector (with zero length), the event is a state. However, identity result vectors can be maintained by balancing forces and counter-forces: for example, when a prop prevents a wall from falling.

Notice that since force and result vectors can form categories – as convex spaces of mappings – a natural extension is that events also form categories, as mappings between action categories and change categories.[8] For example the set of all force vectors involved in pulling a sledge is naturally convex, and so is the set of all paths (change vectors) of moving the sledge to the top of the hill.[9]

The proposed model allows one to represent events at different levels of generality. There are subcategories of events, just as for object categories. For example, *pushing a door open* is that subcategory of *pushing a door*, where the

8 See Gentner and Kurtz (2005) and Zacks and Tversky (2001).

9 However, the question of when a *mapping function* from a convex set of force vectors to a convex set of result vectors can itself be described as convex is complicated.

force vector exceeds the counterforce of the patient. *Pushing a door but failing to open* it is another subcategory, where the counterforce annihilates the force vector.

As we shall show, more vectors and objects may be involved in many event construals. The two-vector model can be seen as a form of basic image schema that can be elaborated by specifying further components.[10] To the minimal representation of an event required by the two-vector condition, a number of other entities ('thematic roles') can be added: agent, instrument, recipient, benefactive, etc.

A limiting case of our event model, expressed linguistically by intransitive constructions such as "Susanna is walking" and "Paul is jumping," is when the patient is identical to the agent. In these cases, the agent exerts a force on him/her/it/self: in other words, the agent modifies its own position in its space of properties.

Our model of a prototypical event is similar to the image schemas used within cognitive semantics: in particular to the force dynamic models proposed by Talmy (1988) and by Croft (2012). We will compare our model to Croft's in section 5.3. It is also related to the *dynamics model* presented by Wolff (2007). He, too, includes a patient and the force vectors of an agent. Since he mainly considers physical movement, he does not model the changes of the patient's properties in a general conceptual space. On the other hand, Wolff considers background forces that we do not include in the basic model (although they show up in some of the event representations).

Unlike many other models of events, we do not explicitly represent the dimension of time in our model. However, since events are dynamic entities, they unfold over time and hence the dimension is implicit in our model. For example, a path implicitly represents time in the order in which changes of states are concatenated.[11]

The spatial structure of our model naturally lends itself to representing the decomposition of events into sub-events in at least two ways. First, events can be decomposed into co-occurring or parallel sub-events using the dimensions of the patient space. Just as in the real world, the conceptual space within which changes happen can be high dimensional. We suggest that an event can be decomposed in co-occurring sub-events when the result vector expresses changes in multiple domains: if two domains are changed, the change can then be seen as two separate events. For example, if a tyre is sliding as well as heating, one may wish to

10 Note that the schema is not visual, but force dynamic (Talmy 1988).

11 It has actually been suggested that time intervals can be construed entities derived from the order of events (Reichenbach 1928, Thomason 1989).

refer to these as separate concurrent events, though they involve the same thing (Bennett 1996). Such decomposition can be driven by the need to reduce representational and computational complexity to cognitively realistic levels: shifts of attention in construals induce one to focus on different sub-events.

Second, events can be segmented sequentially by path subcomponents. As we have shown, a path can be represented as a concatenation of smaller changes for example an icicle falling, breaking and then melting. In this case, the sub-events will be a connected subset of change vectors. While this segmentation can correspond to time intervals, it can also be based entirely on the order of changes in the patient space without explicitly introducing the time dimension.

3.2 Agent and patient

The agent and the patient of an event model are the two most central examples of thematic roles. We model them as objects – albeit sometimes nonmaterial ones – and they can therefore be represented as points in conceptual spaces. The domains of the spaces determine the relevant properties of the agent and the patient.

A patient is an entity: animate or inanimate. The patient is modelled in a *patient space* that contains the domains needed to account for those of its properties that are relevant to the event that is modelled. The properties often include the location of the patient and sometimes its emotional state. A force vector can be associated with the patient: it represents the (counter-)force exerted by the patient in relation to the force vector of the event. This may be a physical force as when a door does not open when pushed; or an intentionally generated force, as when a person counteracts being pushed. In the representation of events, the patient force vector is often unknown and is taken to be prototypical, thereby entailing that the consequences of the force vector of the event are open to various degrees.

An agent is the entity – animate or inanimate – that generates the force vector, either directly or indirectly via an instrument. Although we are not providing a full analysis of causation here, suffice to say that identifying causes with force vectors means that the agent is the one causing something to happen.

An agent is modelled with the aid of an agent space, which minimally contains a force domain in which the action performed by the agent can be represented: this is the agency assumption. The force domain is primarily physical but can be extended metaphorically to social or mental "forces", for example commands, threats and persuasions. The agent space may also contain a physical space domain that assigns the agent a location. In the special case when the patient is identical to the agent – the agent is doing something to itself – the properties of the agent involved in the change must be modelled.

Dowty (1991) presents what he calls *prototypical agents* and *prototypical patients*.[12] Among his list of properties for an agent proto-role one finds *volitional* involvement in the event (p. 572). We will treat this as a default assumption about agents: but, as we shall see, there are also event construals where the agent is non-volitional, for example, when the agent is a natural force such as a storm breaking a tree.

A stronger assumption about an agent is that it is *intentional*. We conceive of intentionality as involving the agent selecting an action in order to reach a goal. The goal is represented mentally by the agent and we model this by introducing a goal space as part of the relevant agent space. There are various ways to model such a space: in the simplest case it might just be a region of the patient space, namely, those states that the agent finds desirable.[13] On this interpretation, intentionality means that the agent chooses actions that are predicted to change the properties of the patient into the goal region. A consequence of this analysis is that an intentional agent must have a representation of the patient space. Of course, similar actions can be triggered by very different goals: a child hammering on a radiator is aiming for a desirable region of the noise domain, while a plumber doing the same action is aiming for a region of the radiator's functional domain of the radiator.

Empirical evidence from child development research supports this general model of events. Firstly, event representations and the understanding of intentionality develop early in infancy (Nelson 1996, Wagner and Lakusta 2009). Michotte's (1963) experiments show also that children assign the roles of agent and patient to moving objects at a very early age. When the agent is animate, children categorize the agent's actions in terms of goals – and not locations or origins (Woodward 1998). In contrast, there is no such bias for inanimate agents (Wagner and Lakusta 2009).

Some event construals involve *recipients* or *benefactors* as thematic roles in addition to the roles of agent and patient. On our analysis, these roles presume

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12 Note that our two-vector model of events – including agents – satisfies most of Dowty's (1991, p. 572) criteria for a proto-agent and a proto-patient. The proto-patient undergoes a change of state, can assume the role of incremental theme and is causally affected by another participant. The proto-agent causes an event or change of state in another participant. We will return to the criterion that the proto-agent is sentient in our analysis of perception verbs.

13 More generally the goal space is the product of *regions* of the patient space with a reward space of the agent. See Gärdenfors and Warglien (to appear).

that the event involves an intention of the agent. We will discuss the role of recipients in relation to intentional verbs in Section 4.6.

This concludes the presentation of our model of event representations. In summary, an event is represented by a number of vectors and a number of entities. The vectors minimally include the force vector and the result vector, but may also include the counterforce of the patient, the force vector exerted by the agent and the intentional goal vector of the agent. The objects include minimally the patient, but may also include the agent and others.

4 The semantics of verbs

4.1 From event representations and construals to language

In this section we will apply our model of events and construals to show that it can form the basis for a general semantics of verbs. In linguistics, the analysis often starts from a particular syntactic feature: then one tries to find that which is semantically common to what this structure expresses. For example Levin and Rappaport Hovav (2005, p. 131) write that their work "is predicated on the assumption that there is a relationship of general predictability between the lexical semantic representation of a verb and the syntactic realization of its arguments."[14] However, it should be clear that no unique path exists from event construals to linguistic realization – different solutions are found in different contexts and in different languages.

Our analysis begins from construals of events. Our aim is to identify *lexicalisation* constraints for verbs. We focus on the meanings of verb roots, since the variety of possible syntactic modifications makes a full semantic analysis of verbs very complicated.

As we have shown in the previous section, a model of an event can be a complex structure, involving not only the two vectors, a patient and an agent with their properties, but also counterforces, instruments, recipients, intentions, etc. Even though the mental model of an event may be complex, (normally) a sentence captures only certain features of a construal generated from a particular focus on the event. By analogy with the visual process – where we can only focus our attention on some features of the visual field – a construal focuses only on

14 Cf. Perlmutter and Postal's (1984, p. 87) Universal Alignment Hypothesis.

certain parts of an event.[15] The sentences "Victoria hits Oscar" and "Oscar is hit by Victoria" describe the same event with the aid of two different construals, where Victoria and Oscar, respectively, are put in focus.[16]

Consequently, no simple mapping exists between the role taken in an event and the designation of subject, object or oblique. A sentence expresses a construal representing a particular focus on an event. Following this idea, the most focussed role is designated subject and the secondary focus is designated object. Givón (2001) calls these *primary* and *secondary topics*. He writes that topicality "is fundamentally a cognitive dimension, having to do with the focus on one or two important event-or-state participants during the processing of multi-participant clauses" (2001, p. 198). As Croft (2012, pp. 252–253) notes, this phenomenon creates problems for all argument realization rules that are based on thematic roles. In agreement with Givón (2001, p. 198), we see topicality not as directly part of event representation, but rather as a central element of the construal process. Our setup provides a structure that solves the problems that arise when event representation and construal are conflated. Speakers have conversational goals in producing construals. The construals are contextual, depending on what the conversation partner already knows or believes or will find most interesting.

4.2 Similarity of verb meanings

We can now compare our theory of verb semantics to other accounts. At the same time, we want to point to some new predictions from the theory. First of all our theory explains *similarities* of verb meanings, by building on the distances between the underlying vectors. The fact that the meaning of *walk* is more similar to that of *jog* than that of *jump* can be explained by the fact that the force patterns representing walking are more similar to those for jogging than those for jumping. Although we have not presented the details of the similarities of the actions involved, these can be worked out systematically from our vectorial representation of actions.[17]

15 This analogy between attentional focusing in visual perception and linguistic highlighting of a mental model carries further, as shown in Gärdenfors (2004).

16 Croft (2012, p. 256) describes the passive voice as a *deprofiling* of the causal chain from the agent to the patient. This can be expressed in our terminology by saying that the patient is made the focus (or topic) of the event.

17 Giese *et al*. (2008) provide one example of how similarities of action can be investigated systematically.

In a parallel way, our model explains the general pattern of the *sub-categorizations* of verbs: For example, the force patterns corresponding to the verbs *march*, *stride*, *strut*, *saunter*, *tread*, etc., can all be seen as subsets (more precisely, sub-regions) of the force patterns that describe *walk*. The inference from e.g. “Oscar is marching” to “Oscar is walking” follows immediately from this inclusion of regions within one another. As far as we have found, no previous theory of verb semantics can account for these two central properties.

Our analysis extends to metaphorical uses of verbs. We claim that an important type of metaphors is based on similarities of force vectors in line with Lakoff’s (1990) “invariance hypothesis”. For example when a football player “scythes down” another player, the metaphor builds on the similarity between the force patterns involved in scything crops and the movement of the first player’s legs in relation to those of the second player. Another metaphor of the same type is when a tennis player “slices” a backhand.

Finding the force invariances involved in such metaphors seems to require a fairly advanced form of abstract thinking. For example, Seston et al. (2009) show that eight-year-old children, but not six-year-olds, can understand such sentences as “When Taylor spilled his milk on the table, he vacuumed it up with his mouth” just as well as adults do. The force vectors involved in vacuuming are sufficiently similar to Taylor’s action with his mouth that the older children can map them onto the situation described in the sentence.

4.3 The single-domain constraint for verbs

Verbs cannot mean just anything. Kiparsky (1997) proposed that a verb can express inherently at most one semantic role, such as theme, instrument, direction, manner, or path. Rappaport Hovav and Levin (2010, p. 25) strengthened this by associating semantic roles with argument and modifier positions in an event schema, and proposed that “a root can only be associated with one primitive predicate in an event schema, as either an argument or a modifier”.

By grounding meanings not in a symbolic event schema (as e.g. do Rappaport Hovav and Levin 1998, p. 109), but in conceptual spaces, we can, by using the cognitive notion of a domain, refine and strengthen the constraints proposed by Kiparsky and by Rappaport Hovav and Levin.

The single-domain constraint: The meaning of a verb (verb root) is a convex region of vectors that depends only on a single domain.

For example, *push* refers to the force vector of an event (and thus the force domain), *move* refers to changes in the spatial domain of the result vector and *heat* refers to changes in the temperature domain.[18] Since our model requires that an event always contains two vectors, the constraint entails that a single verb cannot completely describe an event, but only bring out an aspect of it. However, the two-vector constraint has the testable consequence that a construal can always be expanded to contain references to both the force and result vectors. More precisely, for any utterance based on a construal involving only a force vector, one can always meaningfully ask "What happened?"; and for any utterance based on a construal involving only a result vector one can always ask "How did it come about?"

The single-domain constraint for verbs is analogous to the thesis that adjectives denote convex regions in single domains (Gärdenfors 2000, ch. 5): that is, there are no adjectives that mean e.g. 'red and tall' (multiple domains) and there are no adjectives that mean 'red or green' (not convex). Likewise, there are no verbs that mean 'walk and burn' (multiple domains) and there are no verbs that mean 'crawl or run' (not convex).

The single-domain constraint is all we need to capture Kiparsky's (1997) lexicalisation constraint and Rappaport Hovav and Levin's (2010) reformulation of it. What Kiparsky called different semantic roles correspond, in our model, to concepts in different domains.

The result vector of an event represents the change in the properties of the patient. In general that change can involve multiple properties. For example, when a table is moved, the table not only changes its location: it generates noise and possibly changes temperature. However, the single-domain constraint entails that construals of events only concern changes in one domain. In other words, the focus of attention is on one aspect of the event only.

Admittedly, the strength of the constraint depends partly on how domains are identified (Gärdenfors and Löhndorf 2011). For some areas, it may be problematic to identify the appropriate domain. For example, it may seem difficult to reconcile verbs involving social relations like partying with a single domain. We see it as a research program to analyse the domains presumed by different verbs to test the viability of the single-domain constraint.

An immediate consequence of the single-domain constraint is that no verb can express both the force domain and another type of domain. The literature includes several putative counterexamples, e.g. *climb* (Jackendoff 1985, Goldberg 2010, Kiparsky 1997, Levin and Rappaport Hovav to appear).

18 Possible exceptions to this general rule – which we will discuss later – are verbs that describe changes in ontology (see section 4.4) and verbs like *give* that describe intentional actions involving recipients (see section 4.6).

(1) Oscar climbed the mountain.
(2) Oscar climbed down the mountain.
(3) Oscar climbed along the rope.

It seems that, in its prototypical sense (1) climbing involves both upward motion and manner (clambering), while in other uses (2, 3) the motion has another direction. However, the single-domain constraint is fulfilled by noting that the force vector of *climb* is required to have an upward direction (cf. Geuder and Weisgerber 2002, Levin and Rappaport Hovav to appear). This constraint on the force vector typically generates an upward motion (the result vector), but as (2) and (3) show, exceptions can be made, marked by a preposition describing the direction of the result vector.

(4) The train climbed the mountain.
(5) ?The train climbed down the mountain.

In (4) the force exerted by the train still has an upward direction (though very slanted), but it is only metaphorically a case of clambering. However, in (5) the force exerted by the train no longer has an upward direction and so *climb* is less successfully applied in events of this type.[19] The examples all indicate that the upward direction of the force vector is a prototypical ingredient of the meaning of *climb*.[20]

(6) The snail climbed up the side of the tank.

Levin and Rappaport Hovav (to appear) consider examples like (6) to be counterexamples to the requirement of clambering as part of the meaning of *climb*. However, the snail's use of suction can be seen as a metaphorical form of clambering: the force patterns involved are sufficiently similar.

A fundamental question is: how can the single-domain constraint be cognitively motivated? Why are there no verbs that refer to more than one domain, for example, verbs that cover both the force and result vectors? Our explanation builds on *learnability* constraints: each domain contains an integral set of dimensions that is separable from other domains. A mapping between domains may be

19 However, as Levin and Rappaport Hovav (to appear, p. 11–12) note, uses of *climbing down* exist for trains, buses and planes.
20 What Kiparsky (1997, p. 17) calls disjunctive meaning is thereby not disjunctive at all: instead, the uses have a prototype structure.

hard to learn and subject to many contingencies and sources of instability.[21] In particular, the coupling of force and change vectors is complicated since this concerns the way actions relate to their effects. One's understanding of the patterns of forces exerted by one's arms is well integrated: the movement of an object in three dimensions is likewise integrated, but the relationship between the two is unstable, being subject to external counterforces and other uncontrollable factors. It is therefore difficult to learn.

4.4 Manner and result verbs

Traditionally (Talmy 1975, 1985; Jackendoff 1983, Levin and Rappaport Hovav 1991), there have been two main ways of dividing verbs:

i. manner versus path, as in *jog* versus *cross*; and
ii. manner versus result, as in *wipe* versus *clean*.

A direct consequence of the single-domain constraint is that the distinction between the different kinds of verbs is determined by the domain associated with a verb. If the domain is that of the force patterns underlying actions, it is a manner verb. If the domain is physical space, it is a path verb. If the domain is part of some other category space, it is a proper result verb. Thus the single-domain constraint together with the classification of domains directly predicts these three basic kinds of verbs.

Levin and Rappaport Hovav (Levin and Rappaport Hovav to appear, Rappaport Hovav and Levin 2010) simplify the two divisions to just one by distinguishing between *manner verbs* and *result verbs* – where "manner verbs specify as part of their meaning a manner of carrying out an action, while result verbs specify the coming about of a result state" (Rappaport Hovav and Levin 2010, p. 21). On this distinction, the result verbs now include the path verbs. Rappaport Hovav and Levin claim that any verb "tends to be classified as a manner verb or as a result verb" (ibid., p. 22). Path verbs can be grouped together with verbs that describe property changes because of the tendency to give the same linguistic

21 For example, change in location of a fruit and change of its taste are not correlated. No corresponding domain combines these domains: consequently no verb exists that simultaneously expresses change in location and change of taste. On the other hand, the colour of a fruit and its taste are strongly correlated: therefore it is cognitively economical to introduce the domain of ripeness to capture this correlation. Given this configurational domain (Langacker 1987, pp. 152–154), the verb "ripen" can be introduced to express the correlated changes in the domain.

construction to a changing entity as to a moving one (Pinker 1989, p. 47): both involve changes of properties, which the manner verbs do not.

The distinction is grammatically relevant: the two types of verbs differ in their patterns of argument realization (Rappaport Hovav and Levin 2010, pp. 21–22).[22] To wit, the action described by a manner verb can be augmented, further specifying the event:

(7) Oscar steamed the tablecloth clean/flat/stiff

Here clean/flat/stiff describes the result of the action in different domains.

In contrast, result verbs cannot be augmented with a sub-event from another domain (Rappaport Hovav and Levin 2010, Croft, 2012, p. 297):

(8) *Kelly cleaned the dishes valuable
(9) *Tracy broke the dishes off the table
(10) *Oscar froze the people out of the room

So long as the augmentation of the result stays within the domains that are strongly correlated with the result domain – and thereby expresses changes that are *expected* –, it is acceptable:

(11) Tracy broke the vase into pieces
(12) Oscar froze the ice cream solid

Result verbs describe the changes in the properties of the patient but do not entail how the changes are brought about. The example "I cleaned the tub by wiping it with a sponge/by scrubbing it with steel wool/by pouring bleach on it/by saying a magic chant" from Levin and Rappaport Hovav (2010, p. 222) shows how a result can be brought about in several manners, beside the conventional one. Although result verbs can generate conventional expectations about the corresponding manner, they do not entail them. Conversely, manner verbs do not entail results, although there are general expectations. *Wiping* normally leads to *wiping clean*, but the statement "I wiped the table but none of the fingerprints came off" (Rappaport Hovav and Levin 2010, p. 22) is perfectly acceptable. We can explain this absence of entailments – from manner to result and from result to manner – by

22 Rappaport Hovav and Levin (2010, p. 21) claim that "manner verbs are found with unspecified and non-subcategorized objects in non-modal, non-habitual sentences, result verbs are not." Thus, for example, *"The toddler broke."

the relation of the two kinds of verbs to different domains that are not strongly correlated.

Our vectorial analysis also explains why many result verbs have *antonyms* (*come-go*, *cool-heat*, *grow-shrink*, *fill-empty*, *dry-wet*, *give-take*, *find-lose*). In particular, for any one-dimensional result domain, a verb referring to a vector representing a change in one direction can be complemented by a vector going in the other direction – provided the change process is reversible. (If it is not reversible there can be no such verb: for example there is no *uncook* or *unbreak*). Of course, not all reverse vectors may be lexicalized. In contrast, very few manner verbs refer to force patterns that are reversible directed vectors, and, consequently, antonyms are rare among these verbs.

Putative counterexamples exist to the partition of verbs into these two disjoint classes (Goldberg 2010, Koontz-Garbooden and Beavers, 2012). For example, Goldberg (2010, p. 48) discusses verbs of creation, in particular cooking verbs, that seem to involve both manner and result: "[T]he difference between *sauté*, *roast*, *fry* and *stew* would seem to involve the manner of cooking and yet there is arguably a directed change as well, as the concoction becomes sautéed, fried or stewed." In our opinion, this is an example only of a very strong expectation of the result of the action. Still, when the verb occurs together with an agent it is an intentional manner verb.[23] What complicates the situation is that also unaccusative (anticausative) uses of these verbs exist, for example "The fish is frying" and "The pork is roasting" – where the verb is a result verb. In the unaccusative case, the intentional component of the meaning is absent. These verbs thus have a double use. In each instance, however, they will either be a manner verb or a result verb.

Rappaport Hovav and Levin (2010, p. 28) suggest that the semantic difference between the two categories is that "all result roots specify scalar changes, while all manner roots specify nonscalar changes." They describe a scale as "a set of degrees – point of intervals indicating measurement values – on a particular dimension." Thus they use the notion of a dimension to characterize the difference between manner and result verbs.

However, their proposal has several problems that are avoided by our use of domains and the single-domain constraint. First of all, they must allow two-point scales, which is not much scalarity (for example, the scale for *arrive* is binary). Second, domains are more appropriate than dimensions: e.g. *paint* and *colour* are result verbs that express changes in the three-dimensional domain of colours.

23 In section 4.6, we will return to the role of intentionality in creating double meanings.

Third, we do not see why manner verbs cannot be scalar: in particular when the force vector can be one-dimensional as with *push*.[24]

One class of result verbs is notably problematic for the scalarity hypothesis: it includes those verbs that describe change in the structure of an object, for example *break*, *cut*, *explode*, *burn, eat* and *melt*. They do not represent "scalable" domains – unless binary scales are allowed. Some of them, such as *burn*, *eat* and *melt*, do not express change within a domain but rather change *between* domains. Others, like *break* and *cut*, express changes in the topological properties of objects, such as connectedness. Other verbs in this class, such as *glue*, *couple* and *dovetail*, go in the other direction and connect parts into wholes, All these verbs express higher-level change than is expressible in our basic framework. We cannot elaborate here on how to extend the conceptual spaces analysis to include these cases, but we expect it to be feasible.[25]

Rappaport Hovav and Levin (2010) consider only non-stative verbs in their classification – presumably because their scalarity criterion does not apply to stative verbs. On our analysis, stative verbs are a special case of result verbs where the result vector is the identity vector, corresponding to a point in some property domain.[26] Thus our theory handles these verbs too.

4.5 The role of instruments

Many actions involve *instruments*. The typical case is when the agent uses an instrument to exert the force vector, e.g. hitting with a hammer or cutting with a knife. Instruments are intermediaries between the agent and the force vector acting on the patient. This can be modelled by breaking down the agency into a chain of vectors. In some cases, the linguistic expression of an event focuses on the instrument, e.g. "The hammer broke the window". In such a case the instrument is metonymically made the agent of the event.

Once the thematic roles of agent and patient are represented, it is natural to distinguish between the force vector of the event as applied to the patient and the force vector as generated by the agent. On the second perspective the force vector typically represents an action. An equivalent force vector applied in pushing an

24 Goldberg (2010) makes a similar point concerning *fry*.

25 Many of these higher-level changes could be expressed as state transitions. Such transitions may be explained by the discontinuous effects on the patient space of continuous changes in a force parameter. Thom (1970) classifies the discontinuities into sixteen types of changes.

26 The copula *is* is a generic stative verb that goes together with an adjective or some other way of describing a property.

object (from the patient perspective) may be generated by the performance of very different actions (kicking, shoving, leaning, etc.) described by different patterns of forces exerted by the agent. If an instrument is involved, the force exerted by the agent will be modified by the instrument and thus different from the force vector affecting the patient. Hence, the force vector of the event should be distinguished from the action of the agent. In any more elaborate description of an event, it is not sufficient to represent only the force and change vectors: the action of the agent must also be included.

The difference between the two force vectors shows up linguistically: the causal chain of John kicking the ball and the ball hitting the window can be expressed by

(13) John hit the window with the ball

but not by

(14) *John kicked the window with the ball.

Similarly, the causal chain of Mary litting the fire and the fire heating the water can be construed as

(15) Mary heated the water with the fire

but not as

(16) *Mary lit the water with the fire.

The upshot is that whenever there is an instrument, the force vector applied to the patient (not the one applied by the agent) is the one that is primarily expressed. This accords with our model of events.

The prototypical agent is volitional, while instruments are non-volitional. Yet, in English the instrument can be expressed as the subject:[27]

(17) The hammer hit the nail.

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27 There are other options: In many languages, such as Russian, natural non-intentional forces are normally expressed as obliques with an instrumental case marking (Croft, 2012, p. 264). This accords with the proposal that the vector of a natural force applies directly to the patient.

In this sentence “hammer” is put in focus and functions as an agent. Our analysis is supported by the inability to add a typical agent to the construction:

(18) *The hammer hit the nail by Oscar.

4.6 Intentional verbs

The prototypical action is volitional: hence most manner verbs presume a volitional agent (Dowty 1991, Croft 2012, p. 282). The typical meaning can then be extended to a non-volitional agent as, for example, when *touch* is extended from “Oscar touched the spider” to “The airplane touched the power line”.

A stronger assumption is that the agent is *intentional*, that is, the agent has a representation of a goal that it wants to obtain by acting. The distinction between volitional and intentional sometimes shows up in result verbs. In some cases, a special verb is used to mark an intentional result in contrast to another more neutral verb. The classical case is *kill* versus *murder*. The latter is intentional, while the former is undetermined with respect to intentionality. Thus, *murder* cannot occur with non-intentional agents (Levin and Rappaport Hovav 2005, p. 27):

(19) *The explosion murdered Larry’s neighbour.

Many events involving goals can be construed from either of two perspectives: the physical action on an object or the intentional action leading to the fulfilment of a goal. Such a situation can still be expressed with the aid of a single verb, since the fulfilment of the intention *presupposes* a physical action. Important examples include *give*, *buy* and *sell*. All involve (at least) three entities: agent, object, and recipient. The intentional aspect of such events concerns object ownership (or, more generally, being in control of the object), and the physical aspects of those objects (typically a movement of the object).

In other cases the difference between the intentional and the non-intentional use is not marked by a special verb:

(20) Oscar baked the potatoes for an hour
(21) Oscar baked Victoria a cake

Atkins, Kegel and Levin (1988) distinguish between two senses of *bake*: (i) to change the state of something by dry heat in an oven, exemplified by (20); and (ii) to create by means of changing the state of something by dry heat in an oven), exemplified by (21). The latter is a meronymic change, as discussed above. In the sense (i), *bake* is a manner verb. In sense (ii), it seems to cover both manner and result – seemingly contradicting the single-domain constraint. The contradiction, however, is only apparent. Note that sense (ii) expresses an intentional event involving a transfer of possession, in analogy with *give*. In (21) two construals are combined into a sentence with two patients: Victoria is the benefactive of the intentional action, while the cake is the physical result of the event.[28] Once again, the intentional construal presupposes the physical, so the two construals can be summarized by the intentional. The same ambiguity of meaning can be found in verbs such as *cut*, *brush*, *chop*, *grind* and *mow*. Again, we propose two meanings, involving one intentional and one non-intentional reading.[29]

Goldberg (2011) argues that *accomplishments* – which she defines as "predicates that designate both an activity and the end-state of that activity" – involve two causally related sub-events (see also Dowty 1979 and Rappaport Hovav and Levin 1998).[30] One example is *fill*: "to infuse until full." On our analysis, these verbs are intentional and can therefore generate construals of two sub-events: the intended result, and the manner of achieving the result.[31] Since the intention presumes an action, the verb summarises the two sub-events.

The upshot is that verbs involving intentional actions are not really counterexamples to the single-domain constraint. However, the strong coupling between the two construals creates the illusion that the verb describes both manner and result.

28 Note that the intention of doing something for Victoria is expressed in (21), not the actual transfer (Goldberg 1995). Thus "Oscar baked Victoria a cake, but she did not want it" marks the unexpected lack of transfer.

29 Rappaport Hovav and Levin (2010, p. 37) claim that *cut* is a result verb. In the non-intentional sense it is indeed a result verb, but in its intentional sense, it is a manner verb. The same holds for many verbs with double readings. The examples that Koontz-Garboden and Beaver (2012) propose as counterexamples to the manner/result distinction seem to be of this kind.

30 Garey's (1957, p. 106) original definition of a telic verb is "expressing an action tending towards a goal – envisaged as realized in a perfective tense, but as contingent in an imperfective sense." Here "envisaged" may as well be replaced with "construed". Later, via the influence of Vendler (1957), telic came to mean "with an end-point", but having an end-point is not necessary for an accomplishment (see e.g. Goldberg's (2010) examples 8a and 8b). Our use of "intentional verb" thus brings back Garey's meaning of telic.

31 Thus we cannot fully agree with Goldberg's (2010) analysis, according to which the two subevents can be identified because "the resulting state does not completely overlap temporally with the activity." Rather, the crucial factor is that the resulting state is intentional.

The construal involving the physical result of the action is secondary to the intentional construal, which is described by a manner verb. This primacy shows up when the (telic) intentional construal is complemented with a (non-telic) modifier that applies to the physical result:

(22) *Oscar baked Victoria a cake for an hour.

A similar analysis can be given to dative alternation (see e.g. Pinker 1989, Krifka 1999, Bresnan et al. 2007). Both the sentences “X gave Y the book” and “X gave the book to Y” represent two events: a physical action (the movement of the book) and an intentional one (the change of control or possession). The difference between the two constructions is that the first focuses on the intentional action, the second on the physical event (the intentional goal is specified in the prepositional phrase).

When an intentional event is not part of the construal, the double-object form is not available:

(23) Ann drove the car to Beth
(24) *Ann drove Beth the car (no change of possession or control involved)
(25) Victoria sent the book to Oscar’s home
(26) *Victoria sent Oscar’s home the book (the home cannot be a possessor or controller; see Levin and Rappaport Hovav 2005, p. 62))

What is accepted as an intentional action depends on the context: “Victoria cut Oscar a slice of bread” is more acceptable than “?Victoria cut Oscar a mark on the tree”. The difference is that, in the first case, there is a clear intentional transmission of control (or possession), while in the second it is unclear. This example shows that the verb alone does not determine whether the dative alternation is available: construals of the double aspect events are also involved.[32] On our

32 Languages differ as to when the intentional use of a verb is lexicalised and so can be used in a dative construction. For example, in English (27) is fine (indicating that Oscar now controls the ball), while in Swedish, the equivalent double object construction (28) is not available:

(27) Victoria threw/kicked/hit Oscar the ball.
(28) *Victoria kastade/sparkade/slog Oscar bollen.

A similar difference shows up with respect to the possession of information. In English (29) is acceptable, but in Swedish the equivalent construction (30) is not:

(29) Victoria read/told Oscar the news.
(30) *Victoria läste/berättade Oscar nyheterna.

analysis, the availability of dative alternation is a matter of degree depending on the function of the intentional event in the construal.[33]

4.7 Perception and emotion verbs

We next turn to verbs related to perception and emotion. For these verbs the "forces" involved will be of a different nature than in typical cases. In the perception event expressed by "I hear the owl", *hear* is a result verb that describes a change in the state of the subject (who also functions as the patient in the prototypical event). In this case the subject does not exert a force, i.e. use its effectors: instead the subject is changed through its detectors.[34] In such a situation, the relevant force vector is the action of the sound on the agent.

In contrast, "I listen to the owl" implies an active directing of attention towards the owl. The subject is thus acting as an agent in the prototypical sense.[35] Accordingly, *listen* is a manner verb.[36] Directing one's attention is therefore construed as a case of exerting a force. A similar distinction can be made between *see* (a result perception verb) and *look* (a manner verb) and between *feel* (a result perception verb) and *touch* (a manner verb). *Smell* seems to be ambiguous, alternatively expressing the result and the manner meaning.[37]

Emotion verbs generalize perceptions verbs by describing changes in the emotional rather than the perceptual domain of the patient.[38] Just like the perception verbs, emotion verbs often come in pairs such as *frighten* and *fear* or *please* and *like*. With respect to the first verb in each pair, the experiencer is the patient of something changing his or her emotional state, e.g. "The snake frightens me". In contrast, "I fear the snake", functions in the same way as "I hear the snake":

33 Extensive usage data from Collins (1995) and others suggest that the dative alternation tends to be chosen so that given referents precede non-given ones. Bresnan et al. (2007, p. 75) conclude that "we cannot predict the dative alternation from meaning alone."

34 Thus, "I hear" and "I see" are decausativisations just as "the window breaks." The difference is that the patient now is a sentient being.

35 The distinction was first analyzed by Gruber (1967), albeit in a grammatical setting.

36 In line with our analysis, Croft (2012, p. 23) describes the perceptual verbs as involving a bidirectional transmission of force in mental events.

37 No such polysemy exists in Italian: "sentire un odore" ("feeling an odor") is distinguished from "odorare" or "annusare" ("to smell actively").

38 Several theories of the structure of the emotional domain exist. Most theories contain at least two basic dimensions: a *value* dimension of aspects of emotions, from positive to negative, and an *arousal* dimension of emotional states from calm to excited. See e.g. Russell (1980).

the subject is a recipient of an emotional state.[39] The vector involved is the emotional "impression" of the snake on the subject.

4.8 Adverbs

Verbs refer to vectors in our model. Vectors can vary in terms of dimension, verse (orientation) and magnitude. Therefore, adverbs that are modifiers of verbs should refer to change in these features. For example, in "I speak slowly" the adverb selects one of the several dimensions from the domain of *speak*. "I speak loudly" selects another. In "I walked backward" the adverb refers to the verse of my motion. Finally, in "He pushed the door softly", the magnitude of the force vector representing push is diminished by the adverb. When an action involves a pattern of forces, adverbs can modify the whole pattern by providing dynamic information, for example "she walked limply", "he smiled wryly", or "he kicked aggressively." What is common to these examples is that the adverb restricts the regions associated with the meanings of the verbs. Similarly, in relation to a result verb describing a concatenation of changes (as in a path), an adverb can provide information about the form the path takes, for example, "she crossed the park crookedly".

5 Three conceptualizations of events in linguistics

Our effort to model actions and events is motivated by our use of conceptual spaces as a framework. Our approach has clear connections to the way linguists have conceptualized events in order to understand verb semantics. Among linguistic approaches, three have gained prominence (Levin and Rappaport Hovav 2005, ch. 4): the localist, the aspectual and the causal. The localist approach focuses on motion and location, in physical as well in abstract spaces. The aspectual approach puts the temporal properties of events in the centre. The causal approach highlights the role of causal chains and transmission of force. In this section, we want to show that all three approaches can be subsumed under the general model of events presented here. Our model of events brings out the strengths and limitations of the approaches, while providing a unifying common ground for their central features.

39 Michael Cohen has pointed out to us that "passion" is the etymological cousin of "patient" and means to be moved by emotion.

5.1 Localist approach

Jackendoff's (1976, 1983, 1990) localist hypothesis claims that all verbs are construable as verbs of motion and location (Levin and Rappaport Hovav 2005, p. 80). Clearly conceptual spaces provide a suitable background for locating entities: motion is represented by the result vector. In many cases the motion takes place not in physical space but in abstract spaces. As a consequence, Jackendoff (1990) extends the strict localist approach to distinguish change-of-location verbs from change-of–state verbs, two notions derivable as specifications of result vectors. Even including this distinction, however, the localist approach cannot handle verbs that express the force vectors in a natural way (Rappaport Hovav and Levin 2002). In localist analyses, an agent is treated as a "source". This does not suffice as an explanation of the meaning of manner verbs. We see this as a limitation of the localist approach.

5.2 Aspectual approach

A long tradition within linguistics classifies verbs into aspectual classes by means of the internal temporal properties of the events they express. A classic proposal is that of Vendler (1957) who distinguishes between states, activities, achievements and accomplishments. He uses three contrastive distinctions: stative versus dynamic, durative versus instantaneous, and telic versus atelic. Using these distinctions, the four classes can be described as follows:

- A state is stative, durative and atelic. Example: be in the house.
- An accomplishment is dynamic, durative and telic. Example: build a bridge.
- An achievement is dynamic, instantaneous and telic. Example: realize an error.
- An activity is dynamic, durative and atelic. Example: to walk.

To Vendler's four aspectual classes, many researchers add a fifth: semelfactives – such as *jump*, *knock* or *beep* – that are dynamic, instantaneous and atelic. Originally, Vendler intended his classification to apply to verbs, but aspectual classification really involves event descriptions (Levin and Rappaport Hovav 2005, p. 90).

In our model, the different aspects can be accounted for by describing the properties of the vectors involved in an event. One distinction to be made is whether the vector is *extended* or *punctual*. An extended vector can be decomposed into a sequential composition of vectors (e.g. sub-paths). A punctual one cannot: in other words you can only consider one moment. To some extent, this distinction corresponds to the durative-instantaneous distinction, except that we do not represent the time dimension explicitly in our basic model, for which purpose the decomposition properties of the vectors suffice. Another distinction concerns whether the vector has a fixpoint or not.[40] This corresponds to the telic-atelic distinction.

Given these two distinctions, our theory generates the following classification. In the special case when the relevant vector is the (zero length) identity vector, the event is a stative. The other four cases are illustrated in table 1.

This classification scheme can also be expressed figuratively in terms of vectors (see figure 2):

vector	is extended	is punctual
has fixpoint	accomplishment (build a bridge)	achievement (realize your error)
has no fixpoint	activity (walk)	semelfactive (knock)

Table 1: Classification of aspects.

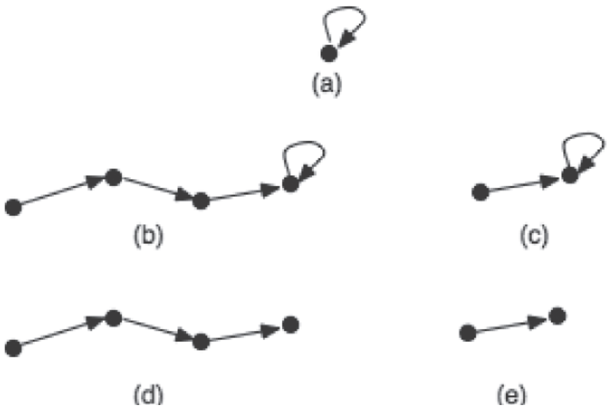

Fig. 2: Aspects as function properties: (a) state, (b) accomplishment, (c) achievement, (d) activity, (e) semelfactive.

a. A state is a point reproducing itself: absence of change.
b. An accomplishment is a series of sub-events leading to a final state (telic).

40 A fixpoint is a point that expresses a stable state. More formally, it is any point where the application of a function or transformation to the point reproduces the point itself.

c. An achievement is like an accomplishment (telic), but consists of only one instant (no temporal structure can be derived from it, beyond a distinction of before and after).[41]
d. An activity is like an accomplishment, except that it does not end in a final state.
e. A semelfactive is an activity happening in one step.

We thus view aspect as primarily functional, not temporal. We make a clear distinction between the representation of an event and the way it is embedded in the time dimension. Our analysis is quite similar to the one proposed by Croft (2012, section 2.3), but it is less detailed. That said, by focusing on vector properties we believe we obtain an even more coherent analysis. For example, Croft includes a temporal dimension, which we do not require.[42]

5.3 Causal approach

Nevertheless, the model that comes closest to ours is Croft's (2012), specifically his "three-dimensional representation of causal and aspectual structure in events."[43] In his earlier work (Croft 1991, 1994), Croft presented a causal model with four basic elements: *initiator*, *cause*, *change* and *state*. The initiator corresponds to the agent in our model, exerting the force vector. His cause is our force vector. His change is our result vector and his state is the endpoint of our result vector. His later work, however, (particularly Croft (2012)) presents a geometrical model that shares many features with ours. His model is perhaps best presented by the example in figure 3.

Two sub-events are represented in this figure: the lower scheme involves two dimensions, q (force) and t (time), where Jack's action is represented as a momentary change in the q-dimension. The upper scheme also involves two dimensions: q (qualitative change) and t (time), where the change of the vase is represented by a change of level along the q-dimension. The arrow from the lower to the upper scheme represents the causal chain. Croft (2012, p. 9) emphasizes that his model is based on geometrically (as opposed to diagrammatically or symbolically) represented components.

41 Mathematically speaking, it is an idempotent map.
42 Langacker's (1987, Section 7.2) analysis of aspect contains basically the same distinctions as Croft's (2012).
43 Langacker's (1986) model has precedence, but it is less developed. He has no notion of vectors and he writes about energy instead of forces.

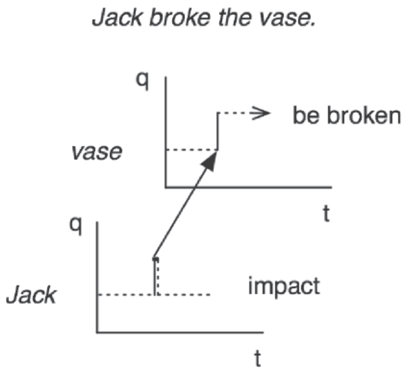

Fig. 3: Croft's representation of "Jack broke the vase" (from Croft, 2012, p. 212. Figure 5.2).

According to Croft, his model demonstrates that "events can be decomposed in three distinct ways: temporally, in terms of the temporal phases; qualitatively, in terms of the states defined on the qualitative dimensions for each participant's sub-event; and causally, in terms of the segments of the causal chain" (Croft 2012, p. 216–217). He points out that dividing an event into sub-events accounts for its causal structure, while the nature of the qualitative changes covers the aspectual structure. In these respects – and furthermore in using a dimensional analysis – his model corresponds with ours.

Despite the obvious similarities between Croft's model of events and our own, certain differences are worth mentioning. Most importantly, our model focuses more on the *geometric* structure of the domains. Croft writes in general about "qualitative" dimensions, but we include their different geometrical and topological properties and sort them into domains. Conceptual spaces provide a more explicit semantic framework for expressing his notion of *quality of states*. In principle, his model can handle the similarities between actions and results – and thereby also the similarities between verbs – but he does not develop this. Another difference from our approach is that Croft does not present a theory of actions to underpin the *force* aspect of the event. Our division between the force and result vectors can be seen as implicit in his model, but he never formulates anything like the single-domain constraint. Furthermore, we require no explicit representation of the time dimension, building everything into the dynamics of the force and result vectors. Together, these differences provide our model with a richer potential for new predictions concerning the semantics of verbs. Croft (2012, p. 219) acknowledges that his model cannot explain these differences since "it only distinguishes causal and non-causal relations on the causal dimension."

Another causal theory is that of Talmy (1972, 1976) who distinguishes between four types of causation: volitional (a volitional entity acts intentionally on a physical object), physical (a physical object acts on another physical object), affective (a physical object acts on a sentient entity), and inductive (a volitional agent acts intentionally on an sentient entity, changing its mental state). It should be clear from the earlier analysis that our model can account for all four types.

This concludes our account of how the three perspectives on verbs discussed by Levin and Rappaport Hovav (2005) are subsumed by our model.

6 Conclusion

Within linguistics, much work in semantics derives from generalizations of some limited set of linguistic data, which are then used to open windows onto underlying cognitive phenomena. In this article, we have followed the reverse path, starting from a general cognitive framework to derive its implications for semantics. We have extended the theory of conceptual spaces to models of actions and events. We expect our model to suggest significant cognitive constraints on lexicalisation processes.

This article can be seen as a step toward providing a cognitive grounding for those word classes that are commonly found in languages. Gärdenfors (2000) outlined the cognitive background for nouns and adjectives. Here we have focused on the semantics of verbs with a brief detour for the semantics of adverbs.

The building blocks for our semantics are two extensions of the theory of conceptual spaces: (i) a model of actions as patterns of forces, and (ii) a model of events as couplings of force vectors (patterns) and result vectors associated to a patient space.

Using these models, our main semantic thesis is that verbs refer to convex regions defined by a single semantic domain (as do adjectives). Together with the framework of conceptual spaces, this approach has allowed us to explain many features of the semantics of verbs. Here we will just summarize some of the main points. First, our models of actions and of property change allow us to predict both similarity of meanings between verbs and the super-subordinate semantic hierarchy of verbs. Traditional semantic theories cannot do this in a natural way. Second, the manner/result distinction falls out immediately from the single-domain constraint. Third, we have highlighted the role of intentionality in verb meaning. We have argued that many verbs that seem to violate the single-domain hypothesis actually have dual lexical potential: one use that includes the intention of the agent (as well as the ensuing result of the action), and one that includes only the result. Fourth, our vectorial approach provides a simple and natural model of the verb aspects proposed by Vendler (1957).

By focusing on vector representations, one obtains a strong tool for systematizing linguistic data. We invite linguists to suggest linguistic generalizations that might extend the scope of application that we have presented in this article. We are aware that there are many problematic examples that could challenge the proposed framework. Such examples may point to cognitive factors that our approach does not capture. In that case, we hope to enter into a dialogue with linguists on how our framework can be extended to handle those cases.

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