Representing actions and functional properties in conceptual spaces

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Abstract

The book *Conceptual Spaces* (Gärdenfors 2000) presents a theory of concepts based on geometrical and topological structures in spaces that are built up from "quality dimensions". Most of the examples in the book deal with perceptual concepts based on dimensions such as colour, size, shape and sound. However, many of our everyday concepts are based on actions and functional properties. For instance most artefacts, such as chairs, clocks and telephones, are categorized on the basis of their functional properties.

After giving a general presentation of conceptual spaces, I suggest how the analysis in terms of conceptual spaces can be extended to actions and functional concepts. Firstly, I will argue that "action space" can, in principle, be analysed in the same way as e.g. colour space or shape space. One hypothesis is that our categorization of actions to a large extent depends on our embodied "perception" of forces. In line with this, an action will be described as a spatio-temporal pattern of forces. When it comes to functional properties, the key idea is that the function of an object can be analysed with the aid of the actions it affords. Functional concepts can then be described as convex regions in an appropriate action space.

Within Cognitive Semantics, image schemas are mainly based on perceptual and spatial dimensions (e.g. Langacker 1987; Lakoff 1987). Two exceptions are Johnson's (1987) and Talmy's (1988) work on "force dynamics" that shows the importance of forces, and metaphorical uses of forces, for the semantics of many kinds of linguistic expression. I shall argue that a more developed understanding on "action space" would allow us to extend the semantic analyses pioneered by Johnson and Talmy. In particular, I shall make a distinction between first-person and third-person perspectives on "forces". My hypothesis is that we start out from an embodied notion of force or "power" that is then extended to forces that are

exerted by other individuals and to forces that act on objects outside our control.

1. The problem of modelling concepts

A central problem for cognitive science is how representations should be modelled. There are currently two dominating approaches to this problem. The symbolic approach starts from the assumption that cognitive systems can be described as Turing machines. On this view, cognition is seen as essentially being *computation* involving symbol manipulation (e.g. Fodor 1975; Pylyshyn 1984; Pinker 1997). The second approach is associationism, where *associations* between different kinds of information elements carry the main burden of representation. Connectionism is a special case of associationism that models associations using artificial neuron networks (e.g. Rumelhart & McClelland 1986; Quinlan 1991). Both the symbolic and the associationist approaches have their advantages and disadvantages. They are often presented as competing paradigms, but since they are used to analyse cognitive problems on different levels of granularity, they should rather be seen as complementary methodologies.

However, there are several aspects of concept formation for which neither symbolic representation nor connectionism seem to offer appropriate modelling tools. In this chapter, I will advocate a third way to represent information that is based on using *geometrical* structures rather than symbols or connections between neurons. Using these structures, *similarity* relations can be modelled in a way that accords well with human (and animal) judgments. The notion of similarity is crucial for the understanding of many cognitive phenomena. I shall call this way of representing information the *conceptual* form since I believe that such representations can account for more of the essential aspects of human concept formation than symbolic or connectionist theories.

Based on my recent book (Gärdenfors 2000), I shall first present a theory of *conceptual spaces* as a particular framework for representing information on the conceptual level. A conceptual space is built up from geometrical representations based on a number of *quality dimensions*. Most of the examples I discussed in my book deal with perceptual concepts based on dimensions such as colour, size, shape and sound. However, there is strong evidence that many of our everyday concepts are based on *actions* and *functional properties*. For instance, most artefacts, such as chairs, clocks and telephones, are categorized on the basis of their functional properties (Nelson 1986; Mandler 2004).

In this chapter, I shall outline how the analysis in terms of conceptual spaces can be extended to functional concepts. Firstly, I will argue that “action space” can, in principle, be analysed in the same way as e.g. colour space or shape space. One hypothesis is that our categorization of actions to a large extent depends on our “perception” of forces. In line with this, an action will be described as a spatio-temporal pattern of forces. I shall also argue that the most cognitively fundamental forces are those that act upon or emanate from one’s own body. In this sense my analysis will be based on an *embodied* perspective.

When it comes to functional properties, the key idea is that the function of an object can be analysed with the aid of the actions it affords. Functional concepts can then be described as convex regions in an appropriate action space. I shall outline a research programme indicating that action space should be seen as a special case of a conceptual space.

2. Quality dimensions

As introductory examples of quality dimensions one can mention temperature, weight, brightness, pitch and the three ordinary spatial dimensions height, width and depth. I have chosen these examples because they are closely connected to what is produced by our sensory receptors (Schiffman 1982). The spatial dimensions of height, width and depth as well as brightness are perceived by the visual sensory system, pitch by the auditory system, temperature by thermal sensors and weight, finally, by the kinaesthetic sensors. However, since there are also quality dimensions that are of an abstract non-sensory character, one aim of this chapter is to argue that force dimensions are important for the analysis of action concepts and functional categories.

Quality dimensions correspond to the different ways stimuli are judged to be similar or different. In most cases, judgments of similarity and difference generate an ordering relation of stimuli (Clark 1993: 114). For example, one can judge tones by their pitch that will generate an ordering of the perceptions. The general assumption is that the smaller the distance is between the representations of two objects, the more similar they are. In this way, the similarity of two objects can be defined via the distance between their representing points in the space. The dimensions form the “framework" used to assign *properties* to objects and to specify *relations* between them. The coordinates of a point within a conceptual space represent particular instances of each dimension, for example, a particular temperature, a particular weight, etc.

The notion of a dimension should be understood literally. It is assumed that each of the quality dimensions is endowed with certain *geometrical* structures (in some cases they are *topological* or *orderings*). As a first example, Figure 1 illustrates such a structure, the dimension of "weight" which is one-dimensional with a zero point, and thus isomorphic to the half-line of non-negative numbers. A basic constraint on this dimension, commonly made in science, is that there are no negative weights.

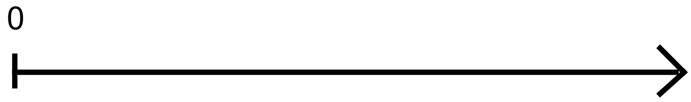

Figure 1. The weight dimension.

A psychologically interesting example of a domain involves *colour perception*. In brief, our cognitive representation of colour can be described by three dimensions. The first dimension is *hue*, which is represented by the familiar *colour circle* going from red via yellow to green and to blue and then back to red again. The topological structure of this dimension is thus different from the quality dimensions representing time or weight which are isomorphic to the real line.

The second psychological dimension of colour is *saturation*, which ranges from grey (zero colour intensity) to increasingly greater intensities. This dimension is isomorphic to an interval of the real line. The third dimension is *brightness* that varies from white to black and is thus a linear dimension with end points. Together, these three dimensions, one with circular structure and two with linear, constitute the colour domain which is a subspace of our perceptual conceptual space. This domain is often illustrated by the so-called *colour spindle* (see figure 2). Brightness is shown on the vertical axis. Saturation is represented as the distance from the centre of the spindle. Hue, finally, is represented by the positions along the perimeter of the central circle. The circle at the centre of the spindle is tilted so that the distance between yellow and white is smaller than the distance between blue and white.

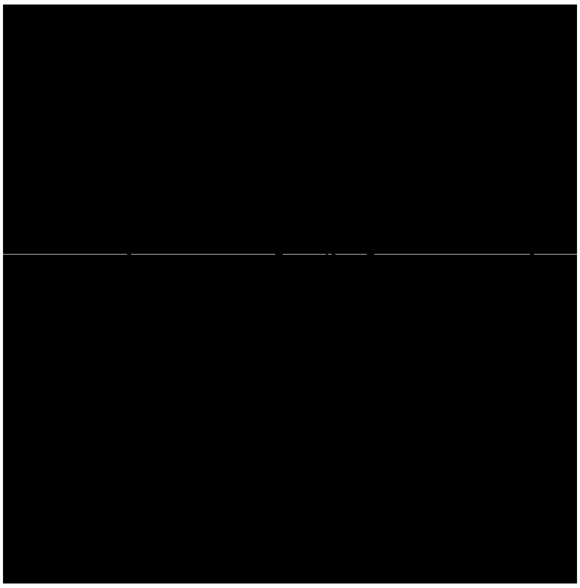

Figure 2. The colour spindle.

A *conceptual space* can now be defined as a collection of quality dimensions. However, the dimensions of a conceptual space should not be seen as totally independent entities, rather they are *correlated* in various ways since the properties of the objects modelled in the space co-vary. For example, in the domain of fruits the ripeness and the colour dimensions co-vary.

It is impossible to provide a complete list of the quality dimensions involved in the conceptual spaces of humans. Some of the dimensions seem to be *innate* and to some extent hardwired in our nervous system, as, for example, colour, pitch, force and probably also ordinary space. Other dimensions are presumably *learned*. Learning new concepts often involves expanding one's conceptual space with new quality dimensions (Smith 1989). Two-year-olds can represent whole objects, but they cannot reason about the dimensions of the object. Goldstone and Barsalou (1998: 252) note:

> Evidence suggests that dimensions that are easily separated by adults, such as the brightness and size of a square, are treated as fused together for children [...]. For example, children have difficulty identifying whether two objects differ on their brightness or size even though they can easily see that

> they differ in some way. Both differentiation and dimensionalization occur throughout one's lifetime.

Still other dimensions may be *culturally* dependent. Finally, some quality dimensions are introduced by *science.* Witness, for example, Newton's distinction between *weight* and *mass*, which is of pivotal importance for the development of his celestial mechanics, but which has hardly any correspondence in human perception. To the extent we have mental representations of the masses of objects in distinction to their weights, these are not given by the senses but have to be learned by adopting the conceptual space of Newtonian mechanics in our representations. In order to separate different uses of quality dimensions it is important to introduce a distinction between a *psychological* and a *scientific* interpretation. The psychological interpretation concerns the cognitive structures (perceptions, memories, etc) of human beings and other organisms. The scientific interpretation, on the other hand, treats dimensions as a part of a scientific theory. The distinction is relevant when the dimensions are seen as cognitive (psychological) entities, in which case their structure should not be determined by scientific theories which attempt to give a "realistic" description of the world, but by *psychophysical* measurements that determine how our concepts are represented.

The conceptual space of Newtonian particle mechanics is, of course, based on scientific (theoretical) quality dimensions and not on psychological dimensions. The quality dimensions of this theory are ordinary space (3-D Euclidean), time (isomorphic to the real numbers), mass (isomorphic to the non-negative real numbers), and force (3-D Euclidean space). In this theory, an object is thus represented as a point in an 8-dimensional space. Once a particle has been assigned a value for these eight dimensions, it is fully described as far as Newtonian mechanics is concerned.

I want to make it clear that the dimensions I consider in my analysis of concepts should be given the psychological interpretation. This applies in particular to the dimension of "force" that will be analysed in the latter sections of this chapter (5–8). A problem for my distinction may be that in Western cultures, the psychological concept of "force" has been tainted by the Newtonian world-view. I will return to this topic in Section 7.

3. Concept formation described with the aid of conceptual spaces

The purpose of this section is to show how conceptual spaces can be used to model *concepts*. I will focus on concepts that are "natural" in the sense that they can, in principle, be learned without relying on linguistic descriptions and, when described, have simple expressions in most languages. A first rough idea is to describe a natural concept as a *region* of a conceptual space *S*, where "region" should be understood as a spatial notion determined by the topology and metric of *S.* For example, the point in the time dimension representing "now" divides this dimension, and thus the space of vectors, into two regions corresponding to the concepts "past" and "future". But the proposal suffers from a lack of precision as regards the notion of a "region". A more precise and powerful idea is the following criterion where the geometric characteristics of the quality dimensions are utilized to introduce a spatial structure on concepts:

Criterion C: A "natural concept" is a convex region of a conceptual space

A *convex* region is characterized by the criterion that for very pair of points v_1 and v_2 in the region all points in between v_1 and v_2 are also in the region. The motivation for the criterion is that if some objects which are located at v_1 and v_2 in relation to some quality dimension (or several dimensions) both are examples of the concept *C*, then any object that is located between v_1 and v_2 on the quality dimension(s) will also be an example of *C*. Criterion C presumes that the notion of *betweenness* is meaningful for the relevant quality dimensions. This is, however, a rather weak assumption which demands very little of the underlying dimensional structure.

Most concepts expressed by basic words in natural languages are natural concepts in the sense specified here. For instance, I conjecture that all *colour terms* in natural languages express natural concepts with respect to the psychological representation of the three colour dimensions. In other words, the conjecture predicts that if some object o_1 is described by the colour term *C* in a given language and another object o_2 is also said to have colour *C*, then any object o_3 with a colour that lies between the colour of o_1 and that of o_2 will also be described by the colour term *C*. It is well-known that different languages carve up the colour circle in different ways, but all carvings seem to be done in terms of convex sets. Strong support for this conjecture has been presented by Sivik and Taft (1994). Their study can be seen as a follow-up of the investigations of basic color terms by Berlin and Kay (1969) who compared and systematized color terms from a wide variety of languages. Sivik and Taft (1994) focused on Swedish color terms, while Taft and Sivik (1997) compared color terms from Swedish, Polish, Spanish and American English. On the other hand, the reference of an artificial colour term like "grue" (Goodman 1955) will not be a convex region in the ordinary conceptual space and thus it is not a natural concept according to Criterion C.[1]

Another illustration of how the convexity of regions determines concepts and categorizations is the phonetic identification of *vowels* in various languages. According to phonetic theory, what determines the quality of a vowel are the relations between the basic frequency of the sound and its formants (higher frequencies that are present at the same time). In general, the first two formants F_1 and F_2 are sufficient to identify a vowel. This means that the coordinates of two-dimensional space spanned by F_1 and F_2 (in relation to a fixed fundamental frequency F_0) can be used as a fairly accurate description of a vowel. Fairbanks and Grubb (1961) investigated how people produce and recognize vowels in "General American" speech. Figure 3 summarizes some of their findings.

As can be seen from the diagram, the preferred, identified and self-approved examples of different vowels form convex sub-regions of the space determined by F_1 and F_2 with the given scales.[2] As in the case of colour terms, different languages carve up the phonetic space in different ways (the number of vowels identified in different languages varies considerably), but I conjecture again that each vowel in a language will correspond to a convex region of the formant space.

Criterion C provides an account of concepts that satisfies the desideratum, formulated by Stalnaker (1981: 347), that a concept "[...] must be not just a rule for grouping individuals, but a feature of individuals in virtue of which they may be grouped". However, it should be emphasized that I only view the criterion as a *necessary* but perhaps not sufficient condition on a natural concept. The criterion delimits the class of concepts that are useful for cognitive purposes, although it may not be sufficiently restrictive.

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1. For an extended analysis of this example, see Gärdenfors (1990).
2. A *selfapproved* vowel is one that was produced by the speaker and later approved of as an example of the intended kind. An *identified* sample of a vowel is one that was correctly identified by 75% of the observers. The *preferred* samples of a vowel are those which are "the most representative samples from among the most readily identified samples" (Fairbanks & Grubb 1961: 210).

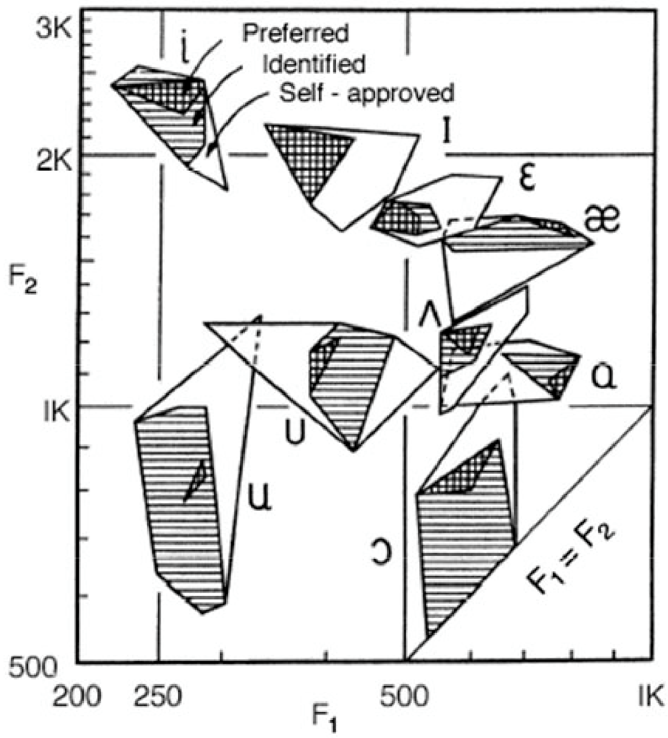

Figure 3. The vowel space of American English (from Fairbanks & Grubb 1961). The scale of the abscissa and ordinate are the logarithm of the frequencies of F_1 and F_2 (the basic frequency of the vowels was 130 cps).

4. Relations to prototype theory

Describing concepts as convex regions of conceptual spaces fits very well with the so called *prototype theory* of categorization developed by Rosch and her collaborators (Rosch 1975, 1978; Mervis & Rosch 1981; see also Lakoff 1987). The main idea of prototype theory is that within a category of objects, like those instantiating a concept, certain members are judged to be more representative of the category than others. For example, robins are judged to be more representative of the category "bird" than are ravens, penguins and emus; and desk chairs are more typical instances of the category "chair" than rocking chairs, deck-chairs, and beanbag chairs. The most representative members of a category are called *prototypical* members. It is well-known that some concepts, like "red" and "bald" have no sharp boundaries and for these it is perhaps not surprising that one finds prototypical effects. However, these effects have been found for most concepts including those with comparatively clear boundaries like "bird" and "chair".

In traditional philosophical analyses of concepts based on truth-conditions or functions from possible worlds to extensions (Montague 1974), it is very difficult to explain such prototype effects (see Gärdenfors 2000, section 3.3).[3] Either an object is a member of the class assigned to a concept (relative to a given possible world) or it is not and all members of the class have equal status as category members. Rosch's research has been aimed at showing asymmetries among category members and asymmetric structures within categories. Since the traditional definition of a concept neither predicts nor explains such asymmetries, something else must be going on.

In contrast, if concepts are described as convex regions of a conceptual space, prototype effects are indeed to be expected. In a convex region, one can describe positions as being more or less *central*. For example, if colour concepts are identified with convex subsets of the colour space, the central points of these regions would be the most prototypical examples of the colour. In a series of experiments, Rosch has been able to demonstrate the psychological reality of such "focal" colours. For another illustration, we can return to the categorization of vowels presented in the previous section. Here the subjects' different kinds of responses show clear prototype effects.

For more complex categories like "bird" it is perhaps more difficult to describe the underlying conceptual space. However, if something like Marr and Nishihara's (1978) analysis of shapes is adopted, we can begin to see how such a space would appear.[4] Their scheme for describing biological forms uses hierarchies of cylinder-like modelling primitives. Each cylinder is described by two coordinates (length and width). Cylinders are combined by determining the angle between the dominating cylinder and the

3. Indeed, the approach to semantics in truth-functional semantics is *anti-psychological* in the sense that the goal is to provide an analysis of the meaning of words and sentences that is independent of human cognition.
4. This analysis is expanded in Marr (1982, Ch. 5). A related model, together with some psychological grounding, is presented by Biederman (1987).

added one (two polar coordinates) and the position of the added cylinder in relation to the dominating one (two coordinates). The details of the representation are not important in the present context, but it is worth noting that on each level of the hierarchy an object is described by a comparatively small number of coordinates based on lengths and angles. Hence, the object can be identified as a hierarchically structured vector in a (higher order) conceptual space. Figure 4 provides an illustration of the hierarchical structure of their representations. It should be noticed that this representation of animal concepts is purely shape-based. Animal concepts depend on many other domains, some of which may be of the functional character that will be analysed in Section 6.

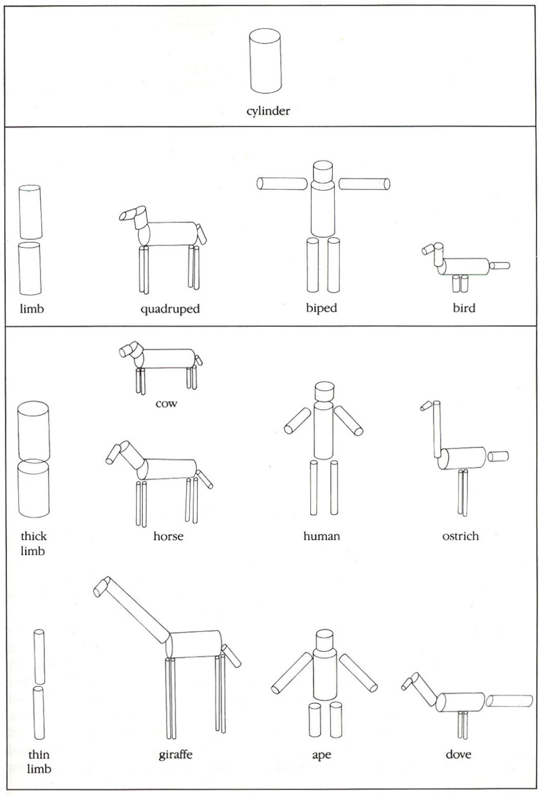

Figure 4. A first-order approximation of shape space (from Marr & Nishihara 1978).

Even if different members of a category are judged to be more or less prototypical, it does not follow that some of the existing objects must represent "the prototype". If a concept is viewed as a convex region of a conceptual space, this is easily explained, since the central member of the region (if unique) is a possible individual in the sense discussed above (if all its dimensions are specified) although it need not be among the existing members of the category. Such a prototype point in the region need not be completely described, but is normally represented as a partial vector, where only the values of the dimensions that are relevant to the concept have been determined. For example, the general shape of the prototypical bird would be included in the vector, while its colour or age would presumably not.

It is possible to argue in the converse direction too and show that if prototype theory is adopted, then the representation of concepts as convex regions is to be expected. Assume that some quality dimensions of a conceptual space are given, for example, the dimensions of colour space described above, and that we want to partition it into a number of categories, for example, colour categories. If we start from a set of prototypes p_1, ..., p_n of the categories, for example, the focal colours, then these should be the central points in the categories they represent. One way of using this information is to assume that for every point p in the space one can measure the *distance* from p to each of the p_i's, that is, that the space is *metric*. If we now stipulate that p belongs to the same category as the *closest* prototype p_i, it can be shown that this rule will generate a partitioning of the space that *consists of convex areas* (convexity is here defined in terms of an assumed distance measure). This is the so-called *Voronoi tessellation*, a two-dimensional example of which is illustrated in Figure 5.

Thus, assuming that a metric is defined on the subspace that is subject to categorization, by this method a set of prototypes will generate a unique partitioning of the subspace into convex regions. Hence there is an intimate link between prototype theory and the proposed analysis where concepts are described as convex regions in a conceptual space.

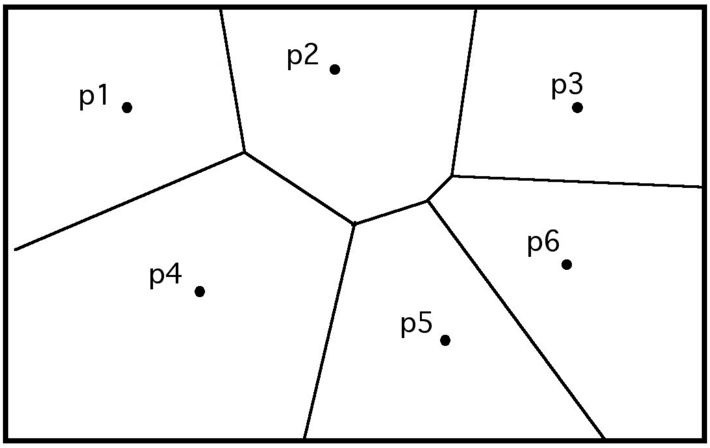

Figure 5. Voronoi tessellation based on six prototypes.

5. Representing actions by forces

So far, the examples have all been of a static nature where the properties modelled are not dependent on the time dimension. However, it is obvious that a considerable part of our cognitive representations concern *dynamic* properties (see, for example, van Gelder 1995; Port & van Gelder 1995).[5] If we, for the moment, consider what is represented in natural languages, *verbs* normally express dynamic properties of objects, in particular *actions*. Such dynamic properties can also be judged with respect to similarities: "walking" is more similar to "running" than to "throwing".

An important question is how the meaning of such verbs can be expressed with the aid of conceptual spaces. One idea comes from Marr and Vaina (1982), who extend Marr and Nishihara's (1978) cylinder models to an analysis of actions. In Marr and Vaina's model an action is described via differential equations for movements of the body parts of, say, a walking human (see Figure 6).[6]

5. To be accurate, van Gelder and his affiliates would avoid using the notion of representation since they associate this with the symbolic approach to cognition. See also the discussion in Johnson and Rohrer (*this volume*).
6. More precisely, Marr and Vaina (1982) only use differential inequalities, for example, expressing that the derivative of the position of the upper part of the

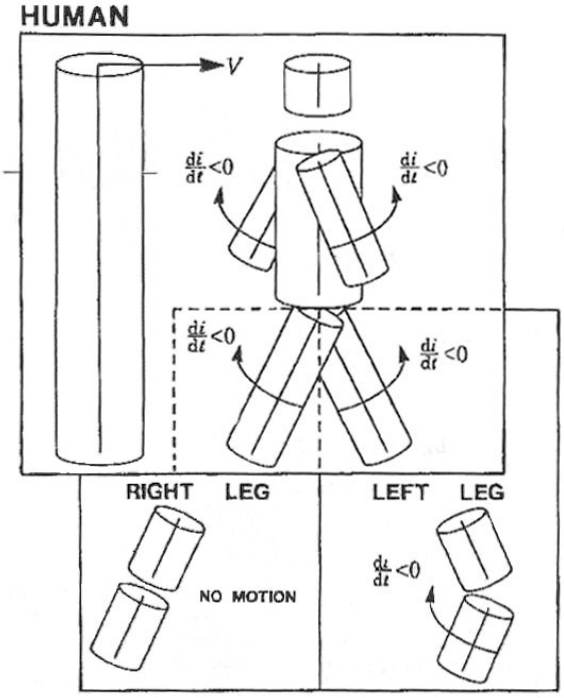

Figure 6. “Walking” represented by cylinder figures and differential equations (from Marr & Vaina 1982).

Applying Newtonian mechanics, it is clear that these equations can be derived from the *forces* that are applied to the legs, arms, and other moving parts of the body. Even though our cognition may not be built precisely for Newtonian mechanics, it appears that our brains have evolved the capacity for extracting the forces that lie behind different kinds of movements and action (see below). In accordance with this, I submit that *the fundamental cognitive representation of an action consists of the pattern of forces that generates it*. However, it should be emphasized that the “forces” represented by the brain are psychological constructs and not the scientific dimension introduced by Newton. The patterns of forces are thus embodied and they can be seen as a form of “mimetic schemas” as discussed by

right leg is positive in the forward direction during a particular phase of the walking cycle.

Zlatev (*this volume*). Such patterns can be represented in principally the same way as the patterns of shapes are described above. For example, the force pattern involved in movements when somebody runs is different from the pattern of a person walking; and the force pattern for saluting is different from that of throwing (Vaina & Bennour 1985).

There is, so far, not very much direct empirical evidence for this representational hypothesis. However, one interesting example comes from phonetics.[7] Fujisaki (1992) has developed a theory of how the fundamental frequency F_0 in speech is generated. He treats the F_0 contour as generated from a linear superposition of two force dimensions that are called phrase and accent commands. The phrase command acts over the intonation phrase, shaped as an initial rise followed by a long fall to an asymptote line. This is generated by a phrase control mechanism, activated by a pulse command with varying magnitude (see Figure 7). The accent command is a local peak on an accented syllable, generated by the accent control mechanism. The two force dimensions are implemented as muscular control of the larynx. On this approach, speech is analysed as a special form of action. In the left part of Figure 7, the two force dimensions are represented on a time scale, where the spurts on the phrase command and accent command dimensions result in the F_0 curve represented in the right part of the figure.

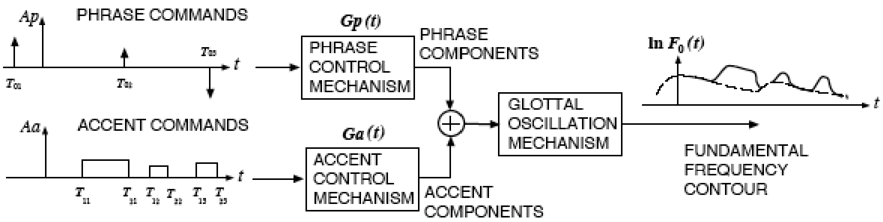

Figure 7. Functional model based on two force dimensions for generating the F_0 contour (from Fujisaki & Ohno 1996).

Another indirect source of empirical support for the representational hypothesis comes from psychophysics. During the 1950's, the Uppsala psychologist Gunnar Johansson developed a patch-light technique for analys-

7. I wish to thank Lauri Carlson for directing me to this theory.

ing biological motion without any direct shape information.[8] He attached light bulbs to the joints of actors that were dressed in black and moved in a black room. The actors were filmed while performing various actions, such as walking, running or dancing. From the films, where only the light dots could be seen, subjects could within tenths of a second recognize the action. Furthermore, the movements of the dots were immediately interpreted as coming from a human being. Later experiments by Runesson and Frykholm (1981, 1983) have shown that subjects can extract subtle details of the action, such as the gender of walkers or the weight of lifted objects (where the objects were not seen on the movies).

One lesson that can be learned from the experiments by Johansson and his followers is that the kinematics of a movement contains sufficient information for identifying the underlying *dynamic force patterns*. Runesson (1994: 386–387) claims that we can directly *perceive* the forces that control different kinds of motion. He argues that one need not make any distinction between visible and hidden properties:

> The fact is that we can *see* the weight of an object handled by a person. The fundamental reason we are able to do so is exactly the same as for seeing the size and shape of the person's nose or the colour of his shirt in normal illumination, namely that *information* about all these properties is available in the optic array.

According to his perspective, the information that our senses, primarily vision, receive about the movements of an object or an individual is sufficient for our brains to be able to extract, with great precision, the underlying forces. Furthermore, the process is automatic – we cannot help but see the forces. Of course, the perception of forces is not perfect – we are prone to illusions, just as we are in all types of perception. He formulates this as a principle of *kinematic specification of dynamics* (the KSD-principle) that says that the kinematics of a movement contains sufficient information to identify the underlying dynamic force patterns.[9]

It goes without saying that this principle accords well with the representation of actions that I have proposed here. One difference is that Run-

8. For a survey of the research, see Johansson (1973).
9. In contrast to humans, recent results of causal reasoning in apes and monkeys indicate that non-human primates often fail to understand the hidden causes, in particular forces, behind certain effects (Povinelli 2000). There seems to be a paucity of research on force perception and how forces affect how we categorize actions.

esson has a Gibsonian perspective on the perceptual information available, which means that he would find it methodologically unnecessary to consider mental constructions such as conceptual spaces. The Gibsonian perspective means that the world itself contains sufficient information about objects and events so that the brain can just "pick up" that information in order to categorise the entity. According to this perspective, mental representations are thus not needed. However, I will here not develop the contrasts between the representational and Gibsonian positions.

Another area where actions and objects show similarities in structure is in the graded structure of the action concepts. There are good reasons to believe that actions exhibit many of the *prototype effects* that Rosch (1975, 1978) has presented for object categories. For example, Hemeren (1997) demonstrated that there is a strong reverse correlation ($r = -.81$) between judgments of most typical actions and reaction time in a WORD-ACTION verification task. He has also shown that subjects in a free listing task of words or phrases for actions show clear effects concerning base level vs. subordinate level concepts (Hemeren 1996). For example, "running" was more frequent and occurred earlier in the lists than "jogging" and "sprinting" and the same applies to "talking" in relation to subordinates such as "whispering" and "arguing".

To identify the structure of the action space, *similarities* between actions should be investigated. However, this can be done with basically the same methods as for similarities between objects.

Even though the empirical evidence is still very incomplete, my proposal is that by adding force dimensions to a conceptual space, we obtain the basic tools for analysing dynamic properties of actions and other movements. As we shall see below, the forces involved need not only be physical forces, but they can also be *emotional* or *social* forces.

6. The cognitive neuroscience of action space

The distinction between perception and action spaces can to some extent be correlated with the findings from neuroscience on how visual information is handled in the brain. Giese and Poggio (2003) note that there is a ventral pathway from the visual cortex that handles form recognition and a corresponding dorsal pathway for motion recognition. These two pathways operate in parallel. Of special interest in relation to my hypothesis, Giese and Poggio speculate that in the dorsal motion pathway there exist neurons (located in the superior temporal sulcus) specialized for motion patterns:

> The representation of motion is based on a set of learned patterns. These patterns are encoded as sequences of "snapshots" of body shapes by neurons in the form pathway, and by sequences of complex optic flow patterns in the motion pathway. (Giese & Poggio 2003: 181)

On the surface, Giese and Poggio's model does not concern dynamics, but kinematics since they describe a sequence of "snapshots" of a movement. Better evidence for dynamic representation of motion comes, for example, from the literature on *representational momentum* (Freyd & Finke 1984). In one of the first experiments on this phenomenon, Freyd and Finke showed subjects a rectangle at three positions in a possible path of orientation. Subjects were told to remember the third orientation and were then presented with a rectangle at a fourth position that was either rotated slightly less, or exactly the same, or slightly more than the remembered triangle (see Figure 8 A). Subjects found it more difficult to detect differences in the direction in the direction of the implicit motion of the sequence of rectangles. This suggests that their mental representations of the

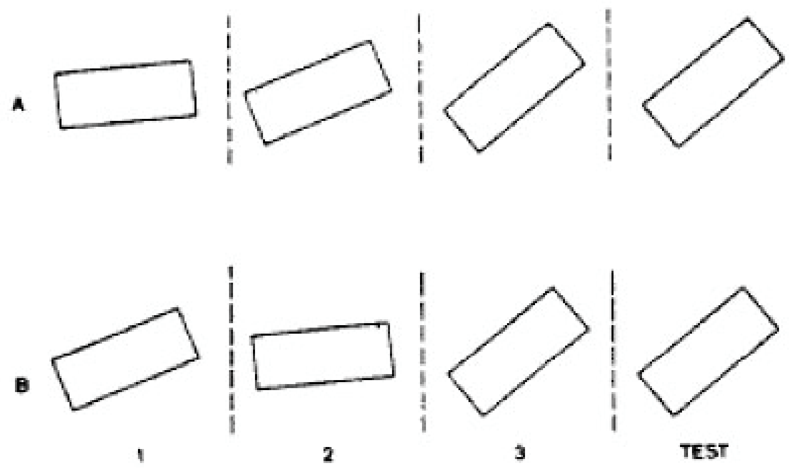

Figure 8. Two experiments on representational momentum (from Freyd & Finke 1984: 128)

rectangles induced a certain “momentum” that influenced their memory of the third triangle. This effect disappeared when the ordering of the two first rectangles was reversed so that the subjects could no longer perceive a path of motion (see Figure 8 B).

Along the same lines, Kourtzi and Kanwisher (2000) showed subjects photos of situations that contained dynamic information. In an fMRI study, they found greater activity in the medial temporal/medial superior temporal region of cortex compared to when subjects were viewing photos with no implied motion. The medial temporal region is one of major brain areas engaged in analysis of visual motion. These glimpses from the cognitive neuroscience of action representations indicate how the brain projects forces, even when the stimuli do not contain any motion. This is a side of “embodiment” that merits further investigation. By combining experiments from cognitive psychology with different kinds of brain imaging, we may hope to acquire the empirical results needed for a more elaborate theory of the structure of action space.

7. Representing functional properties in action space

Another large class of properties that cannot be analysed in terms of perceptual dimensions in a conceptual space are the *functional* properties that are often used for characterizing artefacts. A nice description of the role of functional properties comes from Paul Auster’s novel *City of Glass* (1992: 77):

> Not only is an umbrella a thing, it is a thing that performs a function – in other words, expresses the will of man. When you stop to think of it, every object is similar to the umbrella, in that it serves a function. A pencil is for writing, a shoe is for wearing, a car for driving.
>
> Now my question is this. What happens when a thing no longer performs its functions? Is it still the thing, or has it become something else? When you rip the cloth off the umbrella, is the umbrella still an umbrella? You open the spokes, put them over your head walk out into the rain, and you get drenched. Is it possible to go on calling this object an umbrella? In general, people do. At the very limit, they will say the umbrella is broken. To me this is a serious error, the source of all our troubles.

In agreement with Auster’s intuition, Vaina (1983) notes that when deciding whether an object is a “chair”, the perceptual dimensions of the object, like those of shape, colour, texture and weight, are largely irrelevant, or at least extremely variable. Since I have focused on such dimensions in my description of conceptual spaces, the analysis of functional properties seems to be an enigma for my theory.

I propose to analyse these properties by reducing them to the actions that the objects "afford". To continue with the example, a chair is prototypically an object that affords back-supported *sitting* for one person, that is, an object that contains a flat surface at a reasonable height from the ground and another flat surface that supports the back. In support of this analysis, Vaina (1983: 28) writes: "[T]he requirement for efficient use of objects in actions induces strong constraints on the form of representation. Each object must first be categorized in several ways, governed ultimately by the range of actions in which it can be become involved."

The notion of "affordance" is borrowed from Gibson's (1979) theory of perception.[10] However, he interprets the notion realistically, i.e. as independent of the viewer, while for me the affordances are always identified in relation to a conceptual space, which means that I interpret "affordance" from a cognitivist representational perspective.

In more general terms, I propose that function concepts be interpreted in terms of an *action space*. This is in contrast to the perceptual dimensions that I have presented in my earlier examples in this chapter. To be more precise, I put forward the following special case of Criterion C:

Functional properties are convex regions in action space.

The actions involved in the analysis of a functional property may then, in turn, be reduced to force dynamic patterns as was explained above. This is accomplished by representing a functional property as a vector in a high-dimensional space where most dimensions are constituted of the force dimensions of the action space. In this sense, the functional space is *supervenient* on the action space. Functional properties are thus "higher order properties" in the sense of Gärdenfors (2000, Section 3.10). The main problem with this proposal is that we know even less about the geometry and topology of how humans (and animals) structure action space than we

10. However, as Costall (*this volume)* notes, Gibson's characterization of "affordance" changed over the years.

know about how they structure shape space. This is an area where further research is badly needed.[11]

The upshot of the proposal is that, even if this road of analysis is long and to a large extent unexplored, in principle, functional properties can be explained in terms of more basic dimensions such as forces.

8. The embodiment of forces

In the tradition of Cognitive Semantics, the meanings of expressions have been analysed in semi-geometrical constructs called *image schemas*. In earlier writings, I have shown how these image schemas can be given a more precise description in terms of conceptual spaces (Gärdenfors 1996). For Cognitive Semantics too, the focus has been on the *spatial* structure of the image schema (the very term "image" schema indicates this). Lakoff (1987: 283) goes as far as putting forward what he calls the "spatialization of form hypothesis" which says that the meanings of linguistic expressions should be analyzed in terms of *spatial* image schemas plus metaphorical mappings.

However, there are exceptions to this emphasis on spatial structure. One researcher who at a very early stage brought forward the role of forces in cognitive semantics is Johnson (1987). He argues that forces form perceptual Gestalts that serve as image schemas (even though the word "image" may be misleading here). He writes:

> Because force is *everywhere*, we tend to take it for granted and to overlook the nature of its operation. We easily forget that our bodies are clusters of forces and that *every* event of which we are a part consists, minimally, of forces in interaction. […] We *do* notice such forces when they are extraordinarily strong, or when they are not balanced off by other forces. (Johnson 1987: 42)

Johnson presents a number of "preconceptual Gestalts" for force. These Gestalts function as the correspondences to image schemas but with forces as basic organizing features rather than spatial relations. The force Gestalts he presents are "compulsion", "blockage", "counterforce", "diversion",

11. Within robotics, Chella, Gaglio and Pirrone (2001) use Fourier transforms of motions to represent the movements of objects and of a robot. This solution makes sense from an implementational point of view, but it is uncertain whether the brain uses anything like this to represent actions.

“removal of restraint”, “enablement” and “attraction” (Johnson 1987: 45–48).

Another early exception is Talmy (1988), who emphasizes the role of forces and dynamic pattern in image schemas in what he calls “force dynamics”. He develops a schematic formalism that, for example, allows him to represent the difference in force patterns in expressions like “The ball kept rolling because of the wind blowing on it” and “The ball kept rolling despite the stiff grass”.

Talmy’s dynamic ontology consists of two directed forces of unequal strength, the focal called “Agonist” and the opposing element called “Antagonist”, each force having an intrinsic tendency towards either action or rest, and a resultant of the force interaction, which is either action or rest.

> All of the interrelated factors in any force-dynamic pattern are necessarily copresent wherever that pattern is involved. But a sentence expressing that pattern can pick out different subsets of the factors for explicit reference – leaving the remainder unmentioned – and to these factors it can assign different syntactic roles within alternative constructions. (Talmy1988: 61)

Despite these exceptions, it appears that the role of forces has been underrated within Cognitive Semantics. In Piaget’s theory of sensory-motor schemas, developed for modelling cognitive development and not semantics, motor patterns are central. These can be seen as a special case of the dynamic patterns that form our fundamental understanding of the world. I would suggest that many ideas from the schemas of developmental psychologists can fruitfully be incorporated in the construction used by cognitive semanticists.

Analysing the use of forces in Cognitive Semantics has led me to an ambiguity in the very notion of “force”. In academic circles, Newtonian physics has become a role model for science; and when we speak of “force” it is natural to think of and *represent* them as Newtonian forces – as force vectors in a conceptual space. But when it comes to everyday human thinking, it is important to distinguish between a *first-person* (phenomenological) and a *third-person* perspective of forces.

From the first-person perspective, it is the forces that act directly on you that are considered. These “forces” are not just the physical Newtonian forces, but more importantly also the *social* or *emotional* forces that affect you. It is perhaps more appropriate to call forces seen from a first-person perspective “powers”. First-person powers are *experienced* either as physical forces or as emotional or social pressures that make you move in a particular direction.

From the third-person perspective, one sees forces acting upon an object from the outside, so in this case you don't experience the forces directly, but your perceptual mechanisms derive them. Therefore such forces are not *embodied* in the same way as in the first-person perspective. From the first-person perspective, powers act directly on you, while from the third-person perspective forces act at a distance (*pace* Newton).[12]

One reason for why this distinction is seldom made is that we are extremely good at perceiving forces acting upon other objects.[13] As we have seen in Section 5, the Uppsala school of psychology claims that we can directly *perceive* the forces that control different kinds of motion. According to their Gibsonian perspective, information about the movements of an object is sufficient for our brains to extract the underlying forces.

The importance of this distinction is that our understanding of the third-person perspective presumably *derives* from the first-person person perspective. (This is one reason why Newton had such problems in convincing his contemporaries about forces acting at a distance). If this is the case, then the meanings of words such as *push* and *pull* that are based on first-person powers should be seen as cognitively more fundamental than meanings based on third-person forces. In other words, my hypothesis is that the meanings of the force elements of image schemas are grounded in the actual experience of forces on one's own body.

There is much in Johnson's (1987) book that implicitly points to the centrality of the first-person "power" perspective. For one thing, he focuses on the role of interaction: "[F]orce is always experienced through *interaction*. We become aware of a force as it affects us or some object in our perceptual field" (Johnson 1987: 43). Interaction is primarily seen from a first-person perspective, while forces are abstractions that are seen from a third-person view. Then, in his description of the "enablement" Gestalt or schema, he explicitly focuses on first-person "powers":

> If you choose to focus on your acts of manipulation and movement, you can become aware of a felt sense of power (or lack of power) to perform some

---

12. There is also a second-person perspective where the subject can "put himself in the shoes of the other". This perspective is what is involved in empathy, joint attention and other aspects of a "theory of mind" (see Gärdenfors 2003, ch. 4). Some researchers put forward "mirror neurons" as a possible mechanism behind this perspective (e.g. Rizolatti & Arbib 1998; Gallese 2000)
13. However, it seems that other animal species may not have this capacity to the same extent (Povinelli 2000).

> action. You can sense that you have the power to pick up the baby, the groceries, and the broom but not to lift the front end of your car. While there is no actualized force vector here, it is legitimate to include this structure of possibility in our common gestalts for force, since there are potential force vectors present and there is a definite "directedness" (or potential part of motion) present. (Johnson 1987: 47)

In contrast to Johnson and Talmy, I view social power relations as semantically fundamental, and physical forces that act at a distance from the subject as derived. For example, Winter and Gärdenfors (1995) and Gärdenfors (1998) argue that the meanings of modal verbs are based on social power rather than physical force. Even Talmy (1988: 79) concedes that "[a] notable semantic characteristic of the modals in their basic usage is that they mostly refer to an Agonist that is sentient and to an interaction that is psychosocial, rather than physical, as a quick review can show". I completely agree, but see this as an argument for the primary meaning of the modals being determined by social power relations, while the (few) uses of modals in the context of physical forces are derived meanings.

In a sense, the focus on social power relations makes the conceptual analysis more intricate, because Newtonian force vectors, viewed as natural representations of the third person forces, may not be entirely appropriate to represent the emotional and social aspects of power. Again, more empirical investigations of how human subjects mentally conceive of these powers will be needed.

9. Conclusion

The main purpose of this chapter has been to outline an extension of the theory of conceptual spaces to actions and functional properties. In the first part, I have provided an analysis of concepts with the aid of the notion of conceptual spaces. A key notion is that of a *natural concept* which is defined in terms of convex regions of conceptual spaces – a definition that crucially involves the geometrical structure of the various domains.

As a complement to the perceptual dimensions treated in Gärdenfors (2000), I have in the latter part of the chapter focused on "action space". I submit that action space can, in principle, be analysed in the same way as e.g. colour space or shape space. Admittedly, this will take extensive psychological experimentation to establish. The core hypothesis is that our categorization of actions to build on our perception of forces (which, indeed, seems to be perceptions). The hypothesis is that the cognitive representation of an action can be described as a spatio-temporal pattern of forces. I have argued that functional properties “live on” action space. When it comes to functional properties, the key idea is that the function of an object can be analysed with the aid of the actions it affords. An empirically testable prediction is that functional concepts can be described as convex regions in an appropriate action space. However, there is, so far, not much empirical support for the prediction. Nevertheless, it must be left as a research programme for the time being.

I also believe that conceptual spaces in general and their application to force dimension in particular can be a useful tool to sharpen Cognitive Semantics. With the aid of the topological and geometric structure of the various quality dimensions, one can obtain a more precise foundation for the concept of image schemas that form the core of the theories of e.g. Lakoff (1987), Johnson (1987) and Langacker (1987). I have emphasized the role of forces in image schemas and argued that the first-person perspective on forces is more fundamental than the third-person perspective. I believe that this distinction could also be fruitfully applied within other areas of cognitive semantics.

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