Typicality Effects in the Categorization of Spatial Relations

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Abstract. The chapter provides an overview of linguistic, neuropsychological and experimental psychological approaches and findings that support the idea that spatial relation categories are analog, overlapping, internally structured categories based on prototype comparison and with fuzzy boundaries. The main focus is on viewpoint dependent relations (direction relations) in visuospatial cognition. The notion of a frame of reference in spatial cognition is related to the more general concept of a frame of reference in categorization. Categorization constitutes the bridge between spatial vision and spatial language. For visual space, a spatial framework is proposed that is based on perceptually salient directions which act as standard values in relation to which object relations can be judged.

1 Introduction

The question how we link up spatial expressions with our representations of object relations has received particular attention from cognitive scientists in different disciplines in recent years. This great interest is related to the general theoretically important issue of how language and conceptual representational system map onto each other. It is also motivated by the conceptual primacy of space assumed by cognitive linguistics, and new application needs in domains, such as medicine techniques, navigational systems, Geographic Information Systems, human-machine interfaces to CAD and multimedia systems, and robotics. The general trend toward interdisciplinary research in recent years has opened novel ways to the study of spatial relations and locative terms as well as enhanced the attraction of this field, which is predestined for interdisciplinarity.

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1.1 Background

Our research interests concerning spatial cognition focus on the relation between spatial language and spatial vision. The integration of linguistic and spatiovisual information processing is necessary in the cooperative solution of an assembly task in a certain situation. What cognitive abilities are needed to solve such a task and how they can be transmitted and implemented in artificial communicators is explored in the Special Research Group „Situated Artificial Communicators“ at the University of Bielefeld. Our long-term aim is the development of an integrated system with interacting visual, linguistic, senso-motoric, and other cognitive abilities that can take on the role of the human partner in the accomplishment of assembly tasks. The system is supposed to understand building instructions given by a human and to carry them out. It will be equipped with a stereo camera and has to relate verbal instructions to the observed construction scene. As an empirical basis, a setting has been chosen that involves the cooperative assembly of toy airplanes using a wooden construction kit. In such a setting, communication is situated in a given spatio-temporal context and the processing of visual and linguistically encoded information have to be mapped onto each other. An object's location in space is one of its fundamental attributes and can be used to identify this object. Accordingly, locative specifications are often used in context discriminative object naming (see Herrmann & Grabowski, 1994).

1.2 Spatial Relations

Usually, one object's position is expressed in terms of another one's[2]. That secondary object is used as a reference object. Several factors have been identified to influence the choice of a reference object, as size, mobility, salience, knowledge of speaker and listener, and - in localization sequences - cohesion strategies (see Herrmann & Grabowski, 1994; Herskovits; 1986; Miller & Johnson-Laird, 1976; Talmy, 1983; Vandeloise, 1991). As the localized object and the reference object are usually not interchangeable, spatial relations can be called cognitively asymmetrical. (This can be illustrated by the classic example given by Talmy, 1978. Compare the sentences: THE BIKE IS NEAR THE HOUSE. and: THE HOUSE IS NEAR THE BIKE.)

The visually perceived location is specified by perceived direction and distance (Loomis et al., 1996). Many spatial expressions denote either distance or directional relations. Both types may combine in natural language use (see Schober, 1993). Distance relations are often called ***topological relations*** borrowing the Piagetian metaphor, because this type of spatial relation are independent of the position of the observer (A IS NEAR TO B). In contrast, directional relations appear more bound to the observer. (An object may be located to the left of the observer now, but to her/his right after s/he does an about-face.) Objects are located with respect to each other in

2 In some relations, more than one relatum is used for localizing the intended object, such as between.

terms of their relation to the observer. (A IS TO THE LEFT OF B, or BEHIND B - depending on the position of the observer.) This type of spatial relation moves with the observer (see O'Keefe & Nadel, 1978). Since these are relations in terms of a particular perspective or point of view they are referred to as ***projective relations*** (Moore, 1976). Understanding projective relations requires taking into account the point of viewing.

1.3 Directional Relations and Reference Frames

Our primary focus here is on viewpoint related localizations. Three elements are needed to establish a projective relation: the intended object, a relatum (or reference object), and a point of view (which determines the *frame of reference*). Relatum and point of view may coincide when the relatum possesses an intrinsic orientation (a *two-point* localization, in the terminology of Herrmann, 1990). In that case, the inherent axes of the reference object determine the frame of reference. A different viewpoint is adopted when objects are located with respect to each other in terms of their relation to either a third object, or the observer/speaker, or the addressee (a *three-point* localization; for a systematic taxonomy of horizontal projective relations, see Herrmann, 1990). An overview of classifications and terminology concerning projective prepositions is given in (Retz-Schmidt, 1988).

A variety of vocabulary describing spatial perspective options is used, including *deictic*, *intrinsic*, and sometimes *extrinsic* perspectives (common in psycholinguistics and linguistics) as well as *viewer-centered*, *object-centered*, and *environment-centered* reference frames (mainly in vision research). It is generally agreed that the interpretation of projective relation terms is only possible taking into account the used frame of reference[3] (see Carlson-Radvansky & Irwin, e.g.). The common usage of the term „frame of reference" in spatial cognition research is similar to its use in physics. Consideration of frames of reference is a key element in phenomena involving velocity and displacement or sameness of place (see Bowden et al., 1992; Brewer & Pears, 1993). Suppose that a pair of glasses is on somebody's nose, as they were an hour ago, but an hour ago that person was in a different room in the house. Are the glasses in the same place as they were an hour ago ? (The example has been taken from Brewer & Pears, 1993). Other examples include a ball rolling toward the back of a train that is traveling forward at a constant speed (Bowden et al., 1992) or a pen falling off a table: the viewer can only know which object moved if one of them has a stationary setting within a reference-frame, with respect to which the displacement of

3 In navigation and large-scale space contexts, a common distinction is drawn between egocentric systems of spatial representation in which things are located within spatial frameworks fixed to body parts (the eye, the head, the body, etc.) and an (exo- or) allocentric (maplike) representation that seems to be referenced to the environment. the term. Such a cognitive mapping system enables the organism to move the point of view without actual physical movement in the environment, to view the environment from any vantage point (O'Keefe, 1993; O'Keefe & Nadel, 1978).

the other object receives characterization (Talmy, 1978). There is no way to distinguish uniform motion from rest, neither physically nor in perception. It is purely relative. This „Galilean Principle of Relativity“ has been generalized by Einstein to the „Specific Relativity Principle“ in 1905. In 1632, Galilei wrote (Galilei, 1632, transl. 1967, p. 116):

> *„Motion, in so far as it is and acts as motion, to that extent exists relatively to things that lack it; and among things which share equally in any motion, it does not act, and is as if it did not exist. Thus the goods with which a ship is laden leaving Venice, pass by Corfu, by Crete, by Cyprus and go to Aleppo. Venice, Corfu, Crete, etc. stand still and do not move with the ship; but as to the sacks, boxes, and bundles with which the boat is laden and with respect to the ship itself, the motion from Venice to Syria is as nothing, and in no way alters the relation among themselves.“*

However, the notion of a frame of reference is by no means restricted to the area of spatial cognition. Following its usage in physics, gestalt psychology used the term to describe the fact that an entity in perception is qualified out of its relation to (preceding and concurrent) elements of the whole situation. Important factors are adaptation level and context as well as (dynamically) memorized or physiologically determined standards. Generally, perception and categorization can be understood as scaling w.r.t. a frame of reference (see Thomas, Lusky, & Morrison, 1992, e.g.); examples are contrast effects, differing temperature sensations depending on prior effects, or the judged height of houses. Both, standards given by memory representation and by the actual situation work together in categorizations. All categorizations require reference frames: a set of values to which each given stimulus can be referred; e.g., focal colors in color vision, adaptation levels in velocity perception, or known size distributions of African elephants.
Given the basic notion of a frame of reference for this quite distinct empirical domain as well as for spatial representation, one interesting question to ask is whether these two concepts have something in common and what the connection is between them.

1.4 Direction Terms as Categories: Use of Cognitive Reference Points

In 1925 Wertheimer combined three of his already published papers in a small book: „Drei Abhandlungen zur Gestaltheorie“. One of them (Wertheimer, 1925a) deals with the perception of motion and laid the foundation of a gestalt theory of reference frames; a second one (Wertheimer, 1925b) suggested that among perceptual and abstract categorical entities, there are certain „ideal types“ which act as the anchoring points for perception and thinking. This proposal was taken up in a series of studies by Rosch (1975a). She concluded that focal colors act as *cognitive reference points* in relation to which other colors are judged and argued that such reference points form cognitive „prototypes“ for the categories (Rosch, 1977). Evidence for being internally structured in a similar way was found for different categories, such as geometrical forms (circle, square, and equilateral triangles), judgements of physical distance, and facial expressions (see Rosch, 1977; Smith & Medin, 1981, for a review of the findings). Following Rosch (1977), natural categories can be characterized in terms of prototypes (clearest cases, best examples) and deviations from prototypes; for many categories, the process of categorization can be treated as an analog function, categories having unclear boundaries.

Different studies have shown the relevance of *typicality* (degree of category membership; goodness of example) for the *processing* of a category (Rosch, 1977), for both general attribute domains and categories of concrete objects. Those studies include verification time experiments (e.g., Rips et al., 1973), priming techniques (Rosch, 1975a), order and probability of item output (Rosch, Simpson & Miller, 1976), and the use of linguistic hedges (Rosch, 1975b). When object attributes are only partially correlated or when attributes are continuous, they are cognitively maintained as distinct by being cognitively coded in terms of prototypes and distance from the prototypes (Rosch, 1977).

However, Rosch stressed that „prototypes only constrain but do not specify representation and process models“ (1978, p. 41) and that the „relative typicality of an instance, on her account, could be the result of a variety of structural principles“ (Rips, 1989), e.g., contingency relations, cue validity, central tendency or family resemblance. „Prototypes appear to be just those members of a category which most reflect the redundancy structure of the category as a whole.“ (Rosch, 1977, p. 36). In a somewhat different approach, Reed (1972) has mathematically defined a prototype as the average pattern in a category („that pattern which has for each component x_m the mean value of the mth component of all other patterns in that category“; p. 386f.). According to this definition, a prototype neither needs to be an actual member of the category nor is mathematically equivalent to an average distance model (in which the average distance to the patterns in the category is calculated instead of the distance to the average pattern).

The question of structural principles concerns mainly concrete object categories, formed on the basis of bundles of perceptual and functional attributes. In *attribute categories*, prototypes can be conceptualized as values on a stimulus dimension — physiologically based in some perceptual categories —that serve as reference points in relation to which other stimuli of the domain are judged. We propose that the position of an object relative to a *reference object* or *relatum*, which can be specified in terms of direction, is one of those attribute categories. Direction is similar to categories like color, in that qualitatively differing reference points can be identified (adjectives denoting such attributes are often called „absolute“ in linguistics), in contrast to other spatial domains, such as size attributes, (adjectives referring to them called „relative“, accordingly). Those reference values constituting direction categories include LEFT, RIGHT, IN-FRONT, BEHIND, ABOVE, and BELOW.[4] The LEFT-RIGHT, FRONT-BEHIND, and ABOVE-BELOW axes and their origin (*origo*)

4 Using the geocentric frame of reference would yield to the cardinal directions south, north, west, and east (plus above, and below).

make up the frame of reference; places are individuated by their spatial relations to them.

Linguistic, psychological, and computational considerations suggest that spatial domains are segmented into categories in a manner akin to other categorical structures (Bialystock & Olson, 1987; Hayward & Tarr, 1995; Landau & Jackendoff, 1993; Regier, 1995; Talmy, 1983). There is increasing evidence that spatial categories, such as projective relations, are *not* discrete, mutually exclusive either-or-categories based on critical features with well defined boundaries. Converging experimental and computational results support the idea that projective relation categories are analog, overlapping, internally structured categories based on prototype comparison and with fuzzy boundaries (for an alternative view, see Bialystock & Olson, 1987). In the following sections, we will present some of the evidence that spatial categories, such as projective relations, possess an analog prototype structure and are processed in terms of the prototype and distance from prototype. Furthermore, we will argue that spatial reference frames are a special case of the broader notion of a frame of reference in perception and categorization and that typicality gradients in visuospatial cognition can be put down to the fact that orientation and directional preferences in vision can act as cognitive reference values in relation to which a given spatial relation can be judged. A considerable amount of studies has addressed the question *what* different kinds of reference frames can be employed in spatial cognition; our intention here is to explore *how* one certain frame of reference might be used in categorical judgments on spatial relations. While the intended object is located exactly at one of axes of the reference frame in most studies on the choice of reference frames, we will focus on research on the question how all the deviating positions can be categorized. In these studies, the type of reference frame is usually held constant. We think, verbal object localization will result from an *interaction* of both processes: choice of reference frame and deviation-from-reference-axis computation in many situations (a reference frame might be chosen exactly because of a small prototype deviation).

2 Linguistic Analyses

Talmy (1983) has provided an extensive cross-linguistic study of spatial expressions, aimed „beyond pure description of spatial categories to an account of their common fundamental character and place within larger linguistic-cognitive systems“ (p. 225). His analysis shows that *schematization*, a process involving the systematic selection of particular aspects of a spatial configuration while ignoring the remaining aspects, plays a fundamental role in linguistic space descriptions. Following Talmy’s analysis, the cognitive processes attending schematization involve decision-making (concerning alternatives of schematization and degree of specificity) on the part of the speaker, and image-constructing (depending on this selection) on the part of the listener. Rather than a exhaustive, contiguous array of specific references partitioning a semantic domain, language provides under-specific general terms to refer to different spatial configurations. There is a small number of references in a scattered distribution over a semantic domain, such as spatial relations, providing a *representative* scattering rather than a comprehensive classification. „The particular schematic abstractions that are represented by individual spatial expressions, such as English prepositions, can be called *schemas*“ (Talmy, 1983, p. 258).

The basic properties of schematization include *abstraction*, *idealization*, and a *topological* kind of plasticity. Abstraction and idealization are complementary properties. While idealization refers to the process of conceptually mapping a spatial entity to a schema applied to it (e.g., a pencil or a skyscraper is idealized as a line, when used with the preposition ALONG), abstraction includes disregarding the rest of it (e.g., for the use of ACROSS, it is irrelevant whether an object has or lacks side boundaries, as in the cases of a bed or a river, respectively). According to Talmy, the ACROSS schema can be characterized as a trajectory from one side to another on a level surface bounded by two relatively long parallel edges, forming a right angle to both edges. The term „topology“ is here used to refer to a sort of further abstraction away from any metric specificity as to shape or magnitude of idealized physical objects, also to angles or distances between them. For example, the two edges required for the ACROSS schema, need not be veridical parallel lines; such, ACROSS can be used referring to a path of motion on a lake, where the opposite sides are without uniformity.

The processes of idealization and topology require a cognitive capacity for abstraction and allow for a great flexibility of language. The same spatial configuration can be conceptualized according to alternative schemata; on the other hand, a whole range of spatial configurations has to be captured by the same spatial expression. All possible spatial configurations are to be represented by a small set of expressable schemata. The speaker has to choose the closest available schema in order to linguistically encode a spatial relation. Talmy’s investigation has shown that specific terms are well-distributed over semantic space; they usually do *not* have neighbors of equal specificity: spatial references are not partitioning spatial domains in a contiguous and exhaustive way, but rather are representative of them. It can be concluded from this that the naming of a spatial relation requires a comparison between a given spatial configuration and available schemata (or prototypes; see Rosch, 1977) and that a spatial configuration can deviate from a schema to a variable degree and be more or less typical or representative for a given spatial category (see also, Hayward & Tarr, 1995).

3 Orientation and directional preferences in vision

Given that spatial categories are represented by schemata or prototypes, an important question is what factors determine the positioning of them in semantic space. Talmy (1983) argues that — besides some factors, such as frequency of occurrence or cultural significance — their location must be to a great extent arbitrary, an assumption based on the observed enormous amount of non-correspondence between specific morphemes of different languages. Contrary to this viewpoint, Rosch (1977, e.g.) holds that categories are *not* arbitrary[5] and that the psychological principles underlying the formation of categories are subject to investigation. Categories of concrete objects reflect the high correlational structure objects of the world are perceived to possess, determined by many factors, in particular functional needs (Rosch, 1978) with a variety of structural principles accounting for their formation. However, some attribute categories probably have a physiological basis (Rosch, 1977) and an intrinsic qualitative distinctiveness (Bornstein, 1987). For colors (Berlin & Kay, 1969; Kay & McDaniel, 1978; Kay, Berlin, & Merrifield, 1991), forms (see Rosch, 1977), and tastes (Steiner, 1977), there is evidence that categories originate in and are constrained by perceptually salient stimuli. Hence, an interesting question is whether certain orientations or directions might act as perceptually — possibly physiologically — based cognitive reference points. And indeed, a number of experimental results show evidence for a preference of particular orientations and directions in perception.

Orientation effects in visual perception. Ogilvie and Taylor (1958, 1959) showed for several types of test that visibility of a fine wire is better in a horizontal or vertical orientation than in oblique orientations. Lashley (1938) found that rats could learn to discriminate a horizontal pattern from a vertical one much more easily than a right-oblique from a left-oblique (although the two patterns were separated by 180 degrees in both cases). For both adults and children, similarity judgments have been shown to be easier to make for horizontal and vertical line segments than for diagonal line segments (Arnheim, 1974; Palmer, 1977). Orientation also has a strong influence on the perception of shape; vertically or horizontally oriented areas are preferentially perceived as objects. Symmetry tends to be recognized more easily if related to a vertical axis (Rock, 1973). The described orientation effects show the existence of preferred (i.e., perceptually salient) orientations/directions in the visual system, which might in principal provide reference values for spatial relations within a viewer-centered frame of reference.

Neural mechanisms and representations. The above examples of perceptual orientation saliencies can be found again in neural representation. The visual system provides information on the visual horizontal, the visual vertical, and orientation of lines on several processing levels. The retinotopic mapping is preserved in the visual cortex. The *vertical* meridian of the visual field is represented at the boundary between area 17 (Visual Area I) and area 18 (Visual Area II) of the contralateral hemisphere. This representation of the vertical meridian has been shown to be the boundary between a medial (Visual Area I) and a lateral (Visual Area II) retinotopic

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5 It should be noted here that arbitrariness in the sense of conventionalization is very likely to contribute to the formation of categories, lexical items, and language usage norms in a culture (as exemplified by the preposition use for the spatial relation of a passenger to a bus: in English one says on the bus, whereas in German in the bus is used. The English usage of the platform schema instead of the enclosure schema can historically or diachronically be explained in that it was originally applied to topless carts and stages (Talmy, 1983).

representation of the visual half-field in the cat and the monkey; the vertical meridian being the only retinal region that projects to only one region on the visual cortex. The fovea is represented at the occipital pole. The *horizontal* meridian is represented (in the medial map) at the Calcarine Sulcus with the superior half of the visual field being represented ventrally, and the inferior dorsally, with respect to the calcarine sulcus. Besides the retino-geniculo-cortical projection, there is also a projection of the visual field to the superior colliculi, which are involved in the control of visual orienting reflexes. A retinotopic mapping can be found, in which the *vertical* and the *horizontal* meridians of the visual field cross at the fixation point. Taken together, the perceptual and neural saliency of the visual vertical and the horizontal meridian might account for the intrinsic qualitative distinctiveness of spatial relations reflected in spatial language compared to other spatial attribute domains such as size, length, or distance, in which only quantitative distinctions can be drawn.

Neural selectivity. Contrary to the lateral geniculate body, there is a profound reorganization of the incoming messages in the cortex. One of the features of cortical neurons discovered by Hubel & Wiesel (1959) is their *orientation selectivity*. Whereas some simple cells depend in their reaction on an optimal stimulus (long narrow dark or light rectangles, or edges) of particular orientation and retinal position, complex cells respond to the appropriate axis orientation of an elongated stimulus *irrespective of its exact shape and position*. In a similar way, some visual neurons (ganglions cells as well as simple and complex cells in the visual cortex and visually responsive cells outside area 17) exhibit *directional selectivity* — a preference for stimuli moving in a particular direction. These findings demonstrate the ability of the visual system to abstract spatial information from visual input and the special role of direction/orientation in neural representation.

Spatial encoding. A Euclidean frame of reference for spatially oriented perception and cognition is provided by the three mutual orthogonal canal planes of the (gaze dependent) vestibular system, which is relevant for the perception of the vertical, maintaining an upright posture and visual orientation constancy (Berthoz, 1991). Aligned with these planes of the semi-circular canals are the preferred directions of activation found in a neural network of several parallel pathways that is specialized in the processing of visual motion (Berthoz, 1991; Cohen & Henn, 1988). The vestibular system is one of the factors guiding oculomotor activity, as exemplified by the vestibulo-ocular reflex. The geometry of the canals is paralleled by the directions of the oculomotor system (Berthoz, 1991), which in turn plays an important role in human binocular spatial vision. Rotations of the globe of the eye can occur about the visual axis, the vertical axis and the horizontal axis. Directing the visual axis straight ahead through the crossing point of vertical and horizontal meridian is called the *primary position*, whereas merely vertical or horizontal movements from primary position place the eyes in *secondary position* (all remaining positions are called *tertiary*). Direction of gaze (requiring eye-head coordination) plays an important role in visual localization (Haustein, 1992) and accounts for the obvious capability of fairly accurate judgments of visual directions (see Loomis et al., 1996) - as opposed to distances.

Conclusion. Based on the reviewed evidence, it can be assumed that the reference points constituting direction categories include LEFT, RIGHT, IN-FRONT, BEHIND, ABOVE, and BELOW are related to physiologically anchored preferred directions in perception. The particular LEFT-RIGHT, FRONT-BEHIND, and ABOVE-BELOW axes and their origin (*origo*) establishing a deictic frame of reference depend on the point of view superimposed.

4 Reports from memory

Huttenlocher, Hedges, & Duncan (1991) proposed a model of category effects on reports of particulars and applied this model to the estimation of spatial location. When memory is inexact, schemata may be used as retrieval and reconstruction aid (Bartlett, 1932; Alba & Hasher, 1983). The model proposed by Huttenlocher et al. includes estimation processes combining the (inexactly) remembered stimulus value with category information: boundary values in truncation processes and a prototype value in weighting. They found that people when reporting the location of a dot in a circle spontaneously impose horizontal and vertical lines that divide the circle into quadrants. These lines serve as reference points in that dots are systematically misplaced away from them with distance to them being a strong predictor of bias (being strongest near them). Huttenlocher et al. argue that these reference directions (half-axes from the center to the circumference line) constitute the boundaries of four spatial categories with values near the angular center of each quadrant (neutral towards the horizontal and the vertical axes) at the point of zero bias being their prototypes. It is a somewhat surprising result that the prototypes should lie along the obliques. An alternative account, in our view, might consider the horizontal and vertical half-axes as prototypes (instead of boundaries) and *deviations* from prototypes could be encoded resulting in a cognitive enhancement of these deviations by contrast. This account would attribute the obtained prototype effects rather to encoding than to retrieval processes, contrary to the model proposed by Huttenlocher et al. (1991). A the time being, we are conducting an experiment to explore this hypothesis. Irrespective of what are the precise processing principles producing the obtained categorization data, these data clearly show prototype effects in memorizing angular directions and the use of the vertical and the horizontal axes as reference directions.

For space surrounding oneself, Franklin, Henkel, & Zangas (1995) have shown that spatial categories, named by projective expressions, such as adpositions or adverbs, have fuzzy boundaries, overlap each other, and seem to be defined with respect to their corresponding canonical pole (0°, 90°, 180°, and 270°). They found FRONT — the perceptually and functionally most salient region of surrounding space (see Clark, 1973) — to be largest and to be recalled with the greatest precision. Not only was the absolute error of reported location significantly smaller for FRONT than for other regions but absolute error also increased as a function of distance in degree from the FRONT pole. Furthermore, errors were biased away from the FRONT and BEHIND pole toward LEFT and RIGHT. In terms of typicality effects, the last two findings are the most interesting ones. In an egocentric trunk-centered (subjects were allowed to move head and shoulders) frame of reference, the FRONT/BEHIND axis seems to constitute the most important reference point and to predict error and bias patterns.

5 Linguistic hedges

Natural languages possess means for expressing gradients of category membership. The term „hedges“ has been coined by Lakoff to refer to those qualifying expressions, such as „almost“, „virtually“, or „exactly“ (see Rosch, 1977). Use of hedges was one of the linguistic variables studied in another experiment by Franklin et al. (1995), in which subjects described the directions of objects placed in various *positions around themselves*. Nonspatial qualifiers used by the subjects in their descriptions were rated according to their „emphasis“ on a particular direction (e.g., „directly“ would be rated higher than „almost“, a low value would be assigned to „slightly“ or „kind of“). It was found that emphasis decreases as a function of deviation in degrees from the nearest pole.

We obtained similar results for the categorization of spatial relations in *visual* space (Vorwerg & Rickheit, in prep.). German native speakers were asked to name the spatial position of an intended object with respect to a reference object with no intrinsic orientation. Hedges were used to qualify the degree of direction category membership. According to the experimental setting, there were six distances between located object and reference object. Examples of frequently used hedges dependent on the experimentally varied proximity between the object's location and the vertical/horizontal axis are given in table 1.

Table 1. Hedges used to qualify the degree of direction category membership

German hedge	English translation
genau/exakt; direkt	exactly; directly
fast; fast genau; nicht ganz	almost; almost exactly; not quite
sehr leicht; (ein) bißchen; ein Stück	very slightly; a little bit; a bit
leicht; etwas	slightly; somewhat
versetzt	shifted
schräg	oblique

6 Use of direction terms

Another linguistic measure of typicality of a given direction for a direction category is the proportion of use of direction terms associated with that direction category. Typicality (degree of category membership) should be indicated by a gradient of frequency of use of spatial expressions. Hayward & Tarr (1995) studied the use of vertically and horizontally oriented prepositions in verbal descriptions of a configuration consisting of a reference object (with intrinsic TOP/DOWN axis oriented coaxially to the geocentric and egocentric axes) and an object located at one of 48 systematically varied positions. The authors found a tendency by subjects to use single prepositions (i.e., to assign just one direction category) only in positions that were directly aligned vertically or horizontally with the reference object. An analysis of the proportion use of the respective prepositions generated first in a description revealed a maximum use at locations along the vertical and the horizontal axes, respectively, and a gradual decrease with growing distance from the particular axis. (The absolute level of use as primary descriptor was found to be clearly higher for vertically oriented prepositions.)

We used a similar design to investigate the apprehension of *horizontal* direction categories (front, behind, left, right) in 3D space and did find a gradient of proportion of use, too. In an experimental evaluation of a spatial computational model developed in our research group (Fuhr et al., 1995), subjects were asked to describe spatial configurations consisting of a reference object with no intrinsic sides and another object located in one of 72 positions around the reference object (Vorwerg et al., 1997). Four different orientations (0°, 45°, 90°, 135°) of the (elongated) reference object were studied. A graded use of single directional terms was found for all direction categories in each orientation of the reference object (see Fig. 1). Distance from the nearest reference direction was found to predict the relative frequency of use.

From both experiments follows that spatial relations are not categorized in an all-or-non fashion. Rather, proximity or similarity between a given direction and a cognitively used reference direction is determined. These results hold true for 2D (Hayward & Tarr) as well as for 3D (Vorwerg et al., 1997) space. Comparable gradients were found for the use of direction terms in the vertical (Hayward & Tarr) and in the horizontal (Vorwerg et al., 1997) plane. Additionally, we were able to show that frequency gradients *within* areas adjacent to one side of the reference object. The cognitive reference direction indicated by the best agreement between subjects seems to result from an interaction between point of view and nearest point (edge, corner) of the intended object w.r.t. the reference object (Vorwerg et al., 1997).

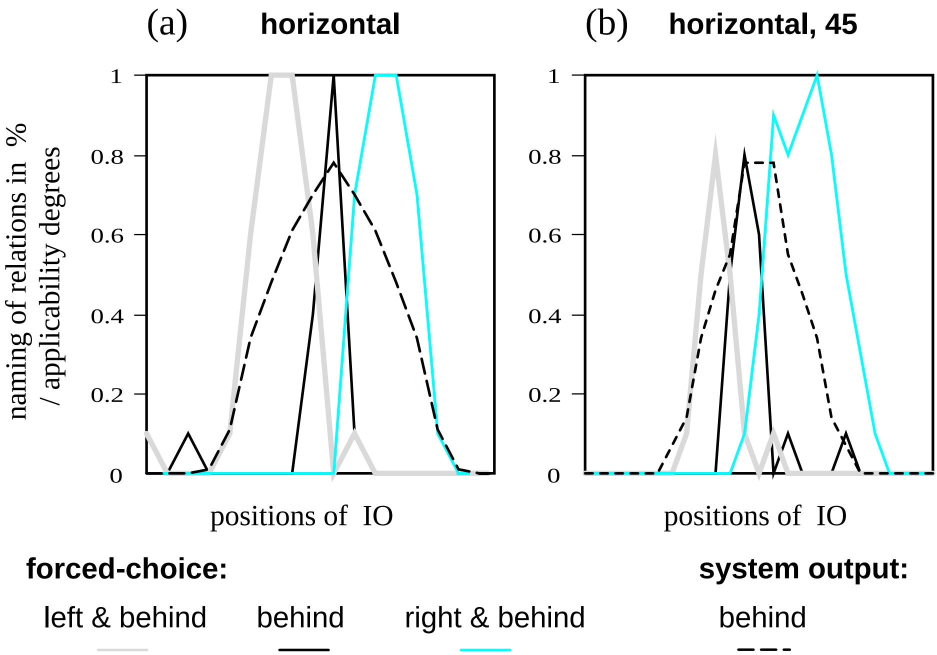

Fig. 1. Acceptability judgments (Vorwerg et al., 1997).

7 Acceptability judgments

Typicality can be described in terms of similarity to representative category members and dissimilarity to representatives of contrasting categories. Several studies have addressed the question of how good projectivec terms are judged to describe a particular spatial relation.

Using the same displays as described in section 5, Hayward and Tarr (1995) asked subjects to provide a rating of goodness of a spatial preposition to describe the relationship between the located object and the reference object. They found predominant regions of acceptability along the horizontal and the vertical axes. Ratings were determined by the distance from the axis and in part by the angle between reference and located object. Following Hayward & Tarr, the predominant regions along the orienting axes can be interpreted as *prototypical regions* for a given spatial term; the applicability of a term at a particular position seems to vary with the distance from the prototypical axis and with the absolute and angular distance to the reference object.

Vorwerg et al. (1997) studied the rated acceptability of horizontal projective terms generated by a system implementation of a spatial computational model (Fuhr et al., 1995). The spatial configurations used were the same as described in section 5. The use of elongated reference objects (bars) allowed to compare the influence of distance from the reference object and distance from the horizontal and sagittal axes, as distances between orientational axis and edges differ according to the orientation of the bar. Locations nearer to the prototypical axis proved to be rated higher in acceptability even if they have the same absolute or angular difference from the edges of the reference object, although equal ratings were predicted by the spatial model.

Gapp (1997) used a radial array of locations around one of differently sized quadratic or rectangular reference objects. His data show a linear decrease of applicability with increase of angular deviation from the respective axis. A projective relation was fully applicable if there was no angular deviation. Ratings depended on the extensions of the reference object. Further, results from this study suggest that it may be proximal angular deviation (to the edge of the reference object) rather than the angular deviation in relation to the center of mass, that underlies projective term acceptability ratings. This parameter had not been varied by Hayward & Tarr, but contradicts the above mentioned finding of Vorwerg et al., that proximity to the axis significantly contributes to the acceptability of a projective term even for locations with the same deviation to the edge of the reference object. Our results suggest that both factors, position of a proximal point of the reference object and proximity to view-point and center-of-mass defined axes, contribute to the applicability of a direction term.

8 Chronometric methods.

Several categorization studies have used tasks that required subjects to verify category membership of a given particular. Responses have found to be faster for items that had been rated more typical (see Rosch, 1977). Those findings „demonstrate that the internal structure of categories has an effect on cognition“ (Rosch, 1977, p. 23). Spatial attention is necessary to map conceptual representations onto perceptual representations of spatial relations (Logan, 1994, 1995). Hence, assuming that prototype effects reflect in some way the conceptual representation of directional categories, reaction times in direction related verification tasks can be predicted to vary with distance from prototypical values.

A reaction time paradigm was applied in an experiment studying the assignment of horizontal projective terms (Vorwerg, 1997). An array of 120 systematically varied positions (11 by 11 with exception of those positions covered by the respective reference object) was used. In each trial, the reference object could have one of four different orientations (0°, 22,5°, 45°, 90°). Objects with no intrinsic front were chosen to avoid the use of conflicting intrinsic and deictic reference frames. The located object was a ring in order to prevent problems of axial alignment with the reference object. A bar was used as a reference object in order to be able to investigate orientation effects (these are not of concern here and will be presented elsewhere). The bar was located at the center of the array. Therefore, five equidistant locations exist at both sides of the reference object. The reference object’s width was approximately the diameter of the ring, its length corresponded five adjacent positions in the array, so that six positions in line with reference object remained (three at each side) on the one hand and five positions existed within the area adjacent to one long side of the bar on the other hand.

Subjects were asked to decide for each possible configuration of one located and one reference object either if the ring is left to the bar or right or neither (LEFT-RIGHT-condition), or if the ring is in front of the bar or behind or neither (FRONT-BEHIND-condition). This task was chosen instead of a simple YES-NO reaction, in order to prevent subjects from simply dividing the whole scene by drawing an imaginary horizontal or sagittal line. One of the results obtained is a significant increase of reaction times with growing distance from the nearest axis (see Fig. 2, 3 showing the overall relations between reaction time and distance for all configurations). It should be noted that reaction time gradients can even be found *within* regions adjacent to a side of the reference object (contrary to what is sometimes suggested in the literature).

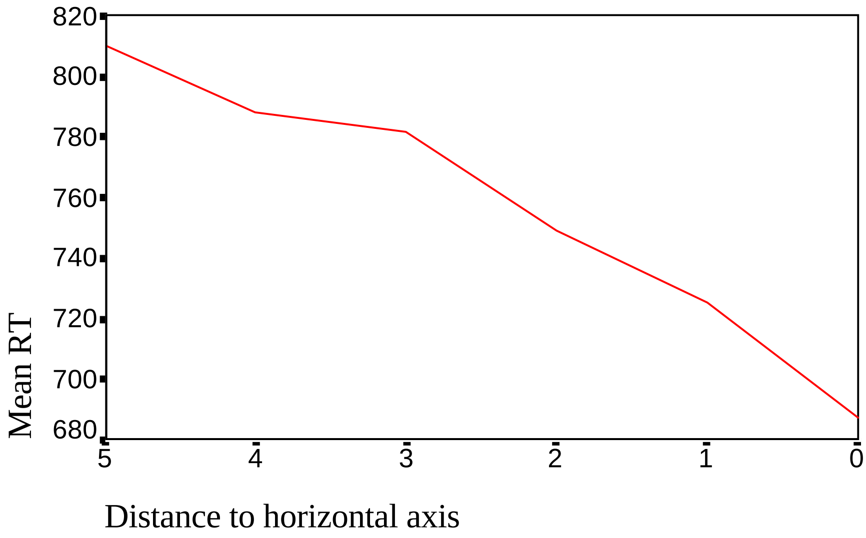

Fig. 2. Verification of left and right. The dependence of reaction time on the distance to the horizontal axis is shown. A value of 0 indicates location at the axis, a value of 5 indicates the furthest location of the intended object

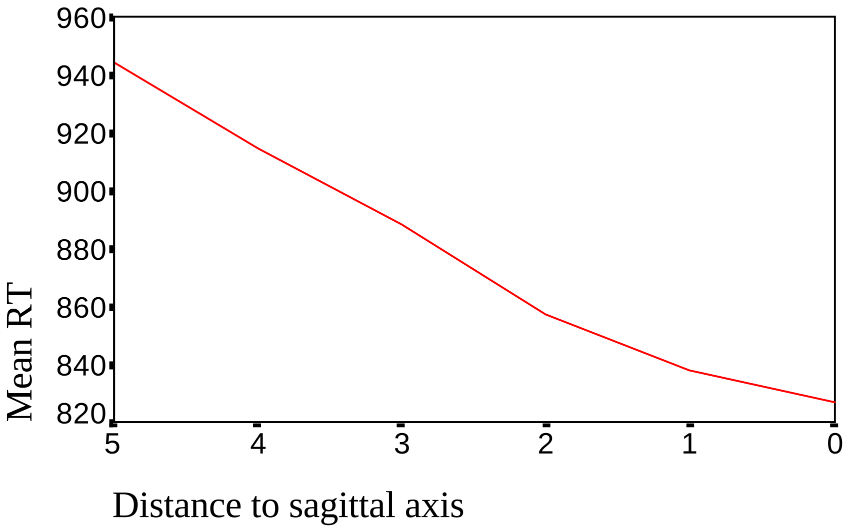

Fig. 3. Verification of front and behind. The dependence of reaction time on the distance to the vertical axis is shown. A value of 0 indicates location at the axis, a value of 5 indicates the furthest location of the intended object

9 Conclusion

In this chapter, we have presented some of the evidence that spatial categories, such as projective relations, possess a graded structure. Several kinds of empirical data suggest an analog structure around perceptually salient prototypes, similar to other (non-binary) attribute domains. A prototype view of spatial categorization is also supported by the prototype effects obtained in a connectionist model (Regier, 1996), although this behavior was not explicitly trained. The model's graded responses to two-object configurations for spatial terms correspond well with empirically found response gradients. Graded applicability of spatial relation terms has found its way into several computational spatial models (e.g., Abella & Kender, 1993; Fuhr et al., 1995; Gapp, 1997).

The perceptually salient prototypes are presumably based on direction/orientation preferences within the visual system (the visual vertical, the horizontal meridian, additionally the obliques might play a smaller role). Factors influencing the membership degree of a given spatial relation to a spatial relation category include the distance from point-of-view and center-of-mass determined axes and the distance from prominent or proximal parts (edges, corners, etc.) of the reference object. Furthermore, an interaction between thus determined deviations from prototypes and the choice of a certain frame of reference. Categorization of spatial relations seems to be guided by the same principles as other kinds of categorization phenomena. Reference objects, in our opinion, do not simply partition space into regions with clear-cut boundaries. Instead, the categorization of a spatial relation can be regarded as a process involving different kinds of information.

It should be noted that categorization is always context-dependent (for instability in category representation, see Barsalou, 1985). The context of confusable alternatives, the functional relation between objects (Carlson-Radvansky & Radvansky, 1996; Coventry, Carmichael, & Garrod, 1994), the purpose of localization (compare identification and exact description) can have an effect on the categorization of spatial relations. The relative importance of reference points may depend not only on the particular task, but also on the point of view determining the frame of reference; such, for some frames of reference, the binocular visual direction (with a cyclopean eye; Mansfield & Legge, 1997) will probably play an important role in determining the FRONT/BEHIND direction (see also, Bühler, 1934). All these factors contribute to the flexible and adaptive nature of categorization as do the changeability of category boundaries and the variability of category assignments of particulars provided by actual comparison processes with situationally, perceptually, and conceptually given points of reference (representatives of cognitive categories).

Our intention in this chapter was to give an overview of empirical results on the question *how* people use frames of reference in visuospatial cognition. A typical finding are gradients of category membership similar to results in other categorization domains. It is concluded that the apprehension of spatial relations can be regarded as a categorization phenomenon. Therefore known categorization effects such as contrast effects can be expected and have been found to occur with spatial cognition. Direction categories are particular in that they seem to be based on visual preferences and show qualitative distinctiveness. The notion of a frame of reference for spatial representation is related to the broader concept of reference frames categorization. For direction relations, the frame of reference is determined by point of view and reference object. It provides the *cognitive reference points* in relation to which object relations are judged.

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