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Spatial cognition strategies in map and diagram reasoning

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The importance of spatial cognition and its intricacies can hardly be overrated. Spatial cognition is, of course, important to the navigation skills of not only human beings, but also many other higher animal species. But more than that, spatial cognition is important for core cognitive tasks like object and pattern recognition, categorization, and reasoning. Most importantly, spatial cognition forms the basis of diagrammatical reasoning, and much points to the fact that diagrammatical reasoning – far from being a derived, secondary type of reasoning or being illustrative only – makes out a core constituent of reasoning. This is argued in the mature Peirce's doctrine of diagrammatical reasoning where the construction and manipulation of ideal, general diagrams is taken to be the central ability of deductive reasoning as such (see Stjernfelt 2007 for the investigation and actualization of this doctrine). The role played by the different tools of spatial cognition thus forms a central task for the further investigation of diagrammatical reasoning in this broad, generalized conception.

The historical development of spatial representation and diagrammatical reasoning systems forms another, genetic perspective on the ontological, structural arguments from diagrammatical reasoning – the development of human culture on the biological basis of primate navigation possibilities. Cassirer (1930), e.g., underlines the very different spatial faculties inherent in what he calls mythical, aesthetical, and theoretical space, respectively. Theoretical space is what we meet in explicity formalized geometries, topologies, and other spatial "ordering systems" of formal and empirical sciences, including the explicit diagrams used and investigated in those sciences. Here, the material basis of spatial cognition is – wholly or partially - abstracted away and purely relational spatial properties are envisaged in their own right. This does not imply an empiricist theory of abstraction, taking abstraction to arise from feature extraction prompted by the repeated exposure to related empirical case. Rather, feature extraction is possible as a stance towards even single empirical perceptions, because general features forms, as it were, already parts, moments, aspects of such perceptions – such as was argued already by the Berliner gestaltists in the beginning of the 20th century. We shall return below to the issue of spatial abstraction. The access to theoretical space, in Cassirer's account, is only possible based on the general life-world substrate of "mythical space" – a conception of space where directions, locations, places, etc. are not yet cleansed for material meanings. This does not imply that mythical space is egocentric (cf. below), rather that aspects of space, be they geo-, allo- or egocentric, are taken to possess ineradicable contents due to contingent empirical contents of such aspects. East is, for instance, taken as a privileged direction due to the sun's rising, it may be seen as the source of light and renewal, while West may be seen as the direction of death, decay and destruction. Certain places where seminal events have happened acquire an inevitable holy meaning, attractive or repulsive, and important landmarks, rivers, mountains,

bridges, etc. are endowed with ineradicable meanings, just like the inhabitants and customs of certain landscapes may colour the perception of them in an inevitable way. To Cassirer, this mythical space is ineradicable and continually informs everyday space perception even to this day – but it forms, on the other hand, the substrate possibility for more sophisticated and explicit elaborations of space construction on the other hand. One is aesthetical space (see Bundgaard in press) where the free generation and investigation of spatial shapes and forms are loosened form the constraints of mythical space and subjected to artistic imagination – precisely because aesthetic space formalizes space and makes possible the investigation of many different possibilities in the distribution of elements in the representation of space. And another such elaboration is theoretical space, both in its universal forms mentioned above and in all the different special sciences, geography, linguistics, biology, physics, cosmology, and many more. To Cassirer, mythical space is pervaded with his most primitive symbol type, that of "Ausdruck", "expression" where form and content never cease to inform each other and effectively flows together – and the elaboration of "higher" space systems is undertaken by logic and language in "presentation" where stable, neutral objects with properties appear, giving room for a larger degree of freedom of thought and art in the combinaiton of objects and properties - and finally by "pure meaning" in formal logic and mathematics – and abstract art? – where even such objects are left behind, and pure, relational meanings remain. Which role does spatial cognition play in this ongoing enlightenment process? Cassirer first tended to assume that the aim of this process, the "pure meaning", was non-spatial, corresponding to the then current idea in philosophy of mathematics that mathematics was basically algebraic, and that geometry was a result of special, derived interpretations of algebra – but towards the end of his life[i] he seemed rather to think that even the most pure meaning had to have a spatial, intuitive aspect, even if highly controlled by theoretical space. Let us try to take Cassirer's idea further by interpreting, in his framework, some recent results in animal and human cognition.

A central issue in spatial cognition is the existence of serveral, competing reference systems facilitating the access to locate the cognizing subject as well as other entities in space. The existence of different reference-systems in language has prompted an interest in charting the extension of these in different languages as well as in finding the cognitive substratum for such systems. Many languages have different lexical systems facilitating the use of such reference systems, falling in three different categories, geocentric, allocentric, and egocentric. Geocentric reference refers to systems with no subjective reference and are often also called objective systems. Examples are *North-South-East-West*, but also local such systems, often referring to major landmarks are examples of geocentricc spatial systems (*Uptown-Downtown – Uphill-Downhill – Up-down the river*, etc.). Its opposite is most often taken to be egocentric reference systems, the most conspicuous of course being *left-right, in front of-behind* referring to the immediate position and orientation of the ego. Thus, egocentric reference depends upon the back-forth *Bauplan* of human beings (which we, of course, share with other vertebrates). The third type of system, allocentric spatial reference,[ii] refers to other entities endowed with such an orientation axis. This immediately comprises other persons and higher animals – we can say that this and that is in front of/ behind him or to his left or right. This also applies to a series of other oriented objects, both of human origin, such as houses, cars,

roads (given a road direction), but also natural objects conceived of as having such an orientation (rivers).[iii]

Even if most languages seem to contain means of referring to all three such spatial orientation types, it seems to be the case, that certain languages "prefer" one over the others; this particularly seems to hold for the geocentric versus the egocentric systems. Thus, Indo-European languages tend to rely much upon egocentric reference-frames, while many other languages (such as the Khoisan language Ha//om from Southwestern Africa, but also other languages from Australia, New Guinea, Nepal, Mexico, etc.) rather rely upon geocentric systems. In such languages, even objects close to the body, e.g. on a table, are referred to after geocentric principles, as being "farther from the ridge" or "closer to the ridge" – where Indo-European languages will typically use egocentric indicators "to the left"/ "to the right". This fact has given rise to the restricted claim of Neo-Whorfianism pointing to this as a fact where the linguistic system does in fact inflict upon the reasoning behaviour its speakers. Experiments thus establish that speakers of Dutch and Ha//om, respectively, prefer egocentric and geocentric interpretation of non-linguistic tasks. The ingenious experiment conducted by among others Daniel Haun and the leading neo-Whorfian Steven Levinson (Haun et al. 2006; Gentner 2007) places five cups in a dice-five pattern on a table, each cup capable of hiding a small object. Behind a screen, a similar pattern of cups is rotated 180 degrees. After having stably learned the place of the object to be found on the one side of the screen, the participants face the same task from the opposite side, so to speak, where they encounter the same pattern of cups. The experimenter is stably standing at the same end of the screen (illustration). This gives three specific choices pointing to either the geocentric, the allocentric, or the egocentric viewpoint. In the first case, the participant will chose the cup which is in the same overall direction as in the first test. In the second case, he or she will chose the cup which is in the same relation to the experimenter, that is, farthest from the experimenter. In the third case, he or she will chose the cup which is in the same relation to his or her own body, that is closest and to the same side after the left-right distinction. The findings are contrasted to a baseline experiment, in which there are objects under all cups – excluding preferences not stemming from the task – and to an experiment where the object is under the middle cup (which is, of course, neutral to all three systems). This experiment solidly establishes the egocentric-geocentric differences between speakers of different languages, in casu Dutch and Ha//om, respectively. The result, however, does not indicate any primitive-developed difference, as might be assumed, which can be seen from the fact that the egocentric system is preferred by languages related to the geocentric ones and spoken not far from them. As to the overall relation between the systems, a strong intuition going all the way back to Kant, takes the egocentric one to be basic, so that allo- and geocentric systems are later, more complicated systems developed on the basis of extrapolations from the egocentric beginning-point. The world, as it were, would be gradually conquered from the basis in subjective experience.

Haun et al. now set up a related experiment in order to gauge the relation of these linguistic preferences to prelinguistic cognition. Here, the same overall setup was used but the sets of cups reduced to three in a line on each side of the screen, thus neutralizing the difference between geocentric and allocentric choices, leaving only the geo-egocentric difference present. This test was now performed with human beings and great apes. The interesting result here showed, that the apes were consistently geocentric in

their approach, while human children differed according to age. Eight-years old children were sufficiently influenced by the language of their culture to display the same consistent choices as that of grownups speaking the same language, while four-years old children, just like the apes, preferred to go for the geocentric solution. This important result points to the fact, that human beings share a basic geocentric orientation system with other primates. The Kantian idea of the privilege of egocentric orientation is thus falsified, and geocentric systems rather seems to be the basic frame of reference – a system, however, which may be modified (or enriched) in language acquisition.. In this (very mild) form of neo-Whorfianism, the influence of language is not determinative of the possibilities of the speaker – rather, it only makes him or her prefer one reference system over the others without precluding access to the other systems. It must be added that the experiments, in using objects within touching distance, favor egocentric reference – thus, it does not imply that the Dutch, egocentrically-referring participants would not change to geocentric reference for tasks featuring remote objects on a larger geographic scale.

In some sense, this important finding ought not to come as a surprise. Both human beings and their ancestors and relatives among higher animals typically live in complicated territories where the ability to find one's way can be decisive for life and death. If you have wandered in days through a territory searching for food – or if you have been chased here and there by a predator – it is little use to know that home (or the preferred habitat of your group, or the best area for fruit gathering, etc.) used to be "to the left" of you. Your body has, of course, turned so many times during your trajectory that its orientation provide no stable cue of your overall geographical situation. The egocentric counterargument would be that your route through the territory is built from a long series of egocentric memories glued together by association, maybe by the relation of a plurality of (some of) these memories to common local landmarks. Such a hypothesis, however, is highly nongeneric and does not account for cases where the subject deviates just a little from previous chains of associations. While it is easy to indicate, by egocentric, left-right means - a route in a human road-system where the distinction between on-road and off-road is evident and stable, this becomes much more difficult in areas without such a system. What would it mean to say "Turn left by the big oak tree" if there is no system of trails, paths, or tracks? In that case it is less confusing to say "Turn towards the ridge by the big oak tree" or "Turn east by the big oak tree."

The weak Whorfian hypothesis where language privileges one orientation system but also allows for the use of the others, opens a research field pertaining to the investigation of the *combination* of the three orientation modes in complicated cognitive tasks. It seems difficult to dispute that such combination is already used by many higher animals, take for instance wolfpacks hunting. When they hunt a moose for hours along a river, it seems to depend on their geocentric knowledge (there does not have to be wolves on the one flank of the hunt; the river takes care of the moose not escaping that way). It also, of course, depends on the single wolf being able to position itself in its immediate surroundings, running left or right around trees and knowing its position relative to fellow hunters to the right and left of him. Finally, it depends on allocentric knowledge – each wolf knows his fellows as well as the prey are oriented beings with a preferred running direction – if the moose suddenly turns around this is an indication he will now shift

running direction. The hunting ability thus seems to be dependent on an online integration of all three kinds of spatial orientation. As simple a task as knowing where you are in the territory, indeed, seems to require no less that the two most important such systems, the geo- and egocentric systems. It is little help to possess an overall geocentric mental map of your territory if you are unable to locate your present position in that map, this requiring that you map your immediate surroundings, including your own body position and orientation, onto that more mediate and general map. But your own position is oriented due to your bodily orientation, and finding yourself on the map involves "turning" your local egocentric representation the right way in order to fit in the immediate surroundings onto their representations on the more general mental map. And you are unable to learn new ways and extend you territorial knowledge if you are unable to glue, as it were, new egocentric experiences onto the more general, geocentric map of overall directions in the territory. The intricate process of grafting geo- and egocentric space representations and forming intermediate representations between them of course require huge cognitive skills. Mandik 2005 proposes that consciousness is simply invented during evolution to resolve this task; it is difficult to evaluate this specific hypothesis, but it is probably right at least to assume that consciousness, once it appears in the animal world, enhances the skill of performing this on-line integration.

A large basis of the human ability for map-reading thus seems to exist in higher animals. Still, an important gap must be bridged. Even if many higher animals seem to possess geocentric environmental maps – including mammals, birds, reptiles, fish, even some insects, e.g. bees, and are able to perform simple diagrammatical reasoning in their mental representations of those maps – no species other than human beings are known to be able to make use of external representations and elaborations of such maps such as topographical maps[iv]. It may be argued that diagrammatical experiments form a very important step in the development of animal intelligence – and the making explicit such diagrams form one of the most important differences between man and other higher animals. What is implied in the construction and use of a map?

In some sense, the basis of a map is the extraction of some subset of the formal structure of the object at issue. Let us take the example of a topographic map as our core example here (not necessarily a map made in the Western cartographic tradition; Polynesian maritime maps may form an equally valid example). The extraction of such features, however, is no simple process. The very basic process in mapmaking of constructing a coastline thus presupposes the complicated task of erecting the very concept of coastline, uniting coastal cliffs, sandy beaches, swamps and many other coast landscape types under one concept based on they forming the limit area towards the sea. This points to an important distinction in such extraction processes highlighted by Peirce's abstraction theory. Here, he distinguishes between different feature extracting processes on the one hand and what he calls hypostatic abstraction on the other. The former takes a phenomenon and isolates one property, letting all other properties indeterminate (here, he distinguishes three subtypes of this process, but this should not occupy us here). Such properties, however, have to be simple, very close to perception – colors, shapes, location, direction, matter etc. In order to access more abstract objects, another process, so-called hypostatic abstraction has to be added on top of feature extraction, making of one such feature a new object of investigation. The extraction of the feature "red" may be abstracted, thus, to the higher-level abstract object of "redness".

Thus, the interplay between extraction and hypostatization forms an important cooperation, facilitating the creation of still more abstract objects. From "redness" may be extracted and hypostazised "color", for instance. Thus, the drawing of a coastline on a map requires the prerequisite of the hypostatization of the concept "coastline" based on "land" and "sea" as the pregnant, non-generic border-region between the two. Similarly, map drawing depends on objects like "lake", "mountain", "road", "house", etc being hypostatically abstracted – so they may, in turn, be given stable representations on the map. Maps, furthermore, require geometrical or topological mappings from the landscape onto the diagram. This does not have to aim at metrical precision (a topological map need not preserve constancy of metrical distance), shape (a map may generalize the shape of landscape objects to very simple shapes far from actual object forms), direction (a map may class directions into a small bundle of simple possible directions) – but *some* constancies have to be selected to be preserved. In a certain sense, the economy of a map may be enhanced by leaving out many such constancies in order to focus upon the simple ones left – cf. subway maps privileging very few directions along with the connectedness of subway lines.

A very important prerequisite for both map making and map using, however, is the intricate interplay between all three spatial representation systems of ego- allo- and geocentric systems. We argued above that all three must be presumed present in higher animals – but what must be added in the case of human diagram construction seems to be the nesting of one within the other by means of hypostatic abstraction. How is it possible to locate one's own position on a topographical map? A decisive operation here is the identification of the ego with one specific localization, one dot on the map. Here, the ego is seen as another – every point on the map represents a possible position of a virtual person, and the location of oneself on the map is the identification of the self with one of these virtual persons. Here, a generalized, hypostatic concept of "other" is nested into the map, and the ego is then identified with one incarnation of this possible other. The position of the ego on the map is a trial-and-error procedure which involves the experiment of placing the ego in different allocentric positions until a position is found which fits with the egocentrically percived immediate surroundings. Thus, the geocentric map contains, nested, the possibility of a general continuity of allocentric positions, one of which is identified with the egocentric position. This position, of course, may be ascertained by the comparison of the empirial egocentric surroundings with those of the position indicated on the map – but this implies, correlatively, that the surroundings of any other possible position on the map may be imagined based on the map's general representation of thorse surroundings. Hypostatical abstraction, necessary for explicit diagram construction as well as for abstract concept formation, thus seems to facilitate the specific nesting of the three basic spatial cognition types to allow for human diagrammatical reasoning.[v]

Already in higher animals, we must assume the constant online integration of ego- and geocentric (and to some extent allocentric) spatial information, in an ongoing trial-and-error process embedding the animal's perpection of its actual location into its geocentric mental map. In human beings, the hypostatic abstraction of explict ideal, general objects facilitate the construction of explicit diagrams in maps, language and other representation systems which makes possible the explicit investigation of the diagram's truthfulness and thus the control of it and ongoing refinement of it. By the

same token, the external diagram facilitates the explicit investigation of non-realized, counterfactual possibilities – constructed out of alternative relational configurations of hypostatized categories.

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[i] Thus in his last article on the development of structuralism where structures seem to possess an ineradicable spatiality.
[ii] Sometimes, geo- and allocentric systems are grouped under one headline and referred to as allocentric.
[iii] There seems to be some confusion about the concepts used to class different frames of reference. Some authors rely merely on the too simple ego-allo distinction. Majid et al. 2004 use the concepts absolute, relative, intrinsic roughly equivalent to the geo-, ego-,

allocentric concepts which the overlapping author group uses in Haun et al. 2007. With respect to “absolute” or “geocentric”, this term is used to group frames of reference which are not equally absolute. North-South-East-West is absolute to the extent that it is derived form sky observations on the sun’s trajectory (or the position of the North Star, or other astronomic objects, etc.) and thus holds for the whole of the surface of the Earth (except from the poles, of course) and is independent of any local landmark. This is not the case for some of the most widely cited examples of geocentric orientations, such as Uphill-Downhill used by Tzeltal speakers in Mexico (or the Manhattan system of Uptown-Downtown). The Tzeltal system, of course, depends on the local position of the community of speakers on the middle of a large ridge slope, giving the general orientation which is valid only locally (but still differs from the ego- and allo-orientations). Thus, “geocentric” seems to refer to different frames of reference, both astronomical, absolute ones and systems dependent on the localization of the speaking community relative to large landmarks (but still independent of the orientation of the individual speaking). Such systems might be desribed as intermediary between absolute, geocentric systems and intrinsic, allocentric systems – they have, like the former, an absolute quality, albeit only locally, and they depend, like the latter, on the orientation of an object, but selects one such, locally dominating, object to be valid for the whole domain of the language spoken.

[iv] Even if von Fritsch’s bee dance, indicating the flight direction relative to the sun position, may said to form a primitive external diagram, it does not have existence beyond the single pointing behaviour and thus does not represent routes not taken.

[v] Pete Mandik has ventured the hypothesis that the very reason for the appearance of consciousness during the process evolution is the integration of geo- and egocentric space representations (Mandik 2005).