Putting Egocentric and Allocentric into Perspective

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Abstract. In the last decade many studies examined egocentric and allocentric spatial relations. For various tasks, navigators profit from both kinds of relations. However, their interrelation seems to be underspecified. We present four elementary representations of allocentric and egocentric relations (sensorimotor contingencies, egocentric coordinate systems, allocentric coordinate systems, and perspective-free representations) and discuss them with respect to their encoding and retrieval. Elementary representations are problematic for capturing large spaces and situations which encompass both allocentric and egocentric relations at the same time. Complex spatial representations provide a solution to this problem. They combine elementary coordinate representations either by pair-wise connections or by hierarchical embedding. We discuss complex spatial representations with respect to computational requirements and their plausibility regarding behavioral and neural findings. This work is meant to clarify concepts of egocentric and allocentric, to show their limitations, benefits and empirical plausibility and to point out new directions for future research.

Keywords: spatial memory, egocentric, allocentric, sensorimotor contingencies, coordinate system, viewpoint-dependent, perspective-free, parietal cortex, hippocampus.

1 Introduction

The Spatial Cognition series started with a seminal paper by Roberta Klatzky ([20]) in which she provided a precise definition for egocentric (i.e., self-to-object) and allocentric (object-to-object) relations, namely self- or object-centered coordinate systems which define relative directions, distances, and bearings. This work has triggered much research examining ego- and allocentricity (e.g., [4], [47], [51]) and we have learned a great deal about these issues. In the following we will firstly summarize some of this work, secondly, compare Klatzky's definition with alternative conceptions of egocentric and allocentric representations with respect to encoding and retrieval, thirdly, discuss limitations of these conceptions, and finally, propose how to combine the existing conceptions in order to solve these limitations.

Humans are able to represent locations egocentrically as well as allocentrically. Depending on the circumstances they seem to prefer the exploitation of one kind of

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relation. Especially three spatial tasks were studied intensely for which we want to present a short overview: scene recognition, reorientation, as well as updating and disorientation.

When *recognizing scenes*, egocentric relations do play an important role. In most of the cases, scenes are recognized better based on an experienced view than on novel views ([9], [25], [37]). However, presenting a novel view interpolating two familiar views from close-by viewpoints can yield even better performance than presenting one of the familiar views ([48]). This suggests a combination of two egocentric representations. However, allocentric relations are also useful in scene recognition. Recognition is influenced by background objects ([5], [28]) or the intrinsic orientation of a spatial array ([27]).

The case is similar for *reorienting* (i.e., self-localizing one's position within a familiar environment after being disoriented). The geometric form of a room plays an important role for this task. This effect was mainly considered to arise from allocentric representations of the room ([4], [52]). However, simulations have shown that many of the experimental results can be explained by view matching as well which encompasses egocentric relations ([40]). Nevertheless, starting from five years of age, children begin reorienting by the (allocentric) structure of an object and not just by matching views ([29]).

A typical example of a task where egocentric relations are used is *updating*. When moving around, egocentric locations in the environment have to be updated. Although updating processes are always possible sources of errors, they are sufficiently accurate to detect changes to an object array equally well from a familiar viewpoint as from an updated novel viewpoint ([37]). However, navigators also encode allocentric relations. Since allocentric relations are independent from the own position, their representation does not need to be updated during own movement and is even preserved after disorientation. These allocentric relations encompass the shape of a surrounding room or a sufficiently familiar object array ([16], [47], [51]). Regular arrays seem to be represented more often allocentrically, whereas irregular layouts more likely egocentrically ([53]). When becoming more familiar with an array, a switch between precise egocentric to a more imprecise allocentric representation seems to take place ([47]).

The insights gained about scene recognition, reorientation and updating clearly show the usefulness of a precise definition of allocentric and egocentric relations. This definition allowed, first, identifying the format of spatial representations in experiments which thus, second, revealed under which circumstances navigators profit from which relation. However, egocentric and allocentric can be conceptualized not only as coordinate systems and need not be conceived of as mutually excluding conceptions. In the next section we will introduce two alternative formats of representation in addition to coordinate representations and will discuss how egocentric and allocentric representations may be encoded and retrieved.

2 Elementary Spatial Representations

An elementary conception is a spatial representation which, first, encompasses only one kind of relation (either egocentric or allocentric), and second, expresses locations relative to one (or no) point of reference. Therefore, egocentric and allocentric coordinate systems as introduced above are kinds of elementary spatial representations. In addition, we will now introduce sensorimotor representations (which form a second kind of elementary egocentric representation) and perspective-free representations (which form a second kind of elementary allocentric representation). We will then discuss processes of constructing and using these elementary representations and point out their limitations.

2.1 Egocentric Representations

2.1.1 Sensorimotor Contingencies

Following O'Regan and Noë[1] ([32], [33]; see also [45]) representing an object in a certain distance and direction means knowing how the sensory input will change when performing actions. It is the contingencies between action and perception within which a location is represented. Navigators know how their visual input on the retina will change when they move around. This change depends on the distance and the direction to the object. For example, distant locations result in smaller changes on the retinal picture when stepping one meter to the side than proximal locations. Sensorimotor contingencies are representations in a perception-action format. Navigators use them to deal with their environment, but not necessarily to communicate or think about it. As our perceptions and actions are always relative to our self (or to body parts), sensorimotor contingencies are egocentric representations.

Campbell ([8]) argued that "true" egocentric representations (in a philosophical sense) are to be distinguished from merely body-centered representations, the latter being representations where in principle the body could be any body (it only "happens to be mine"). Spatial representations based on sensorimotor contingencies are truly egocentric in this sense, since they represent spatial locations by (possible) actions (e.g. how to reach them or how to move to see them; see also [44], [45]). Since they represent actions (and not just spatio-temporal trajectories, which would make them merely body-centered), they do not encompass an explicit representation within a coordinate system, opposed to the following conception.

2.1.2 Egocentric Coordinates

In this conception introduced by Klatzky ([20]), spatial locations are explicitly represented within a coordinate system centered on the navigator (Fig. 1 left side). For navigation purposes, centers of coordinate systems will typically be the torso. Locations in a plane are specified by two parameters such as angle and distance relative to the current body orientation. In such a way each location is represented by an individual body-centered vector. Egocentric bearing (i.e., the angle between self-orientation and the orientation of another object) requires an additional parameter in the 2D case. Relations such as distance, relative direction, or relative bearing between two non-self

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[1] The sensorimotor account of vision is an account of (conscious) visual experience by far not limited to spatial representations. It was worked out in detail in Noë ([30]). Although the authors do not agree with the general claim of O'Regan and Noë (namely that every conscious experience can be explained in this way; see also [35], [46] for critique), the basic idea can be fruitfully applied to spatial representation.

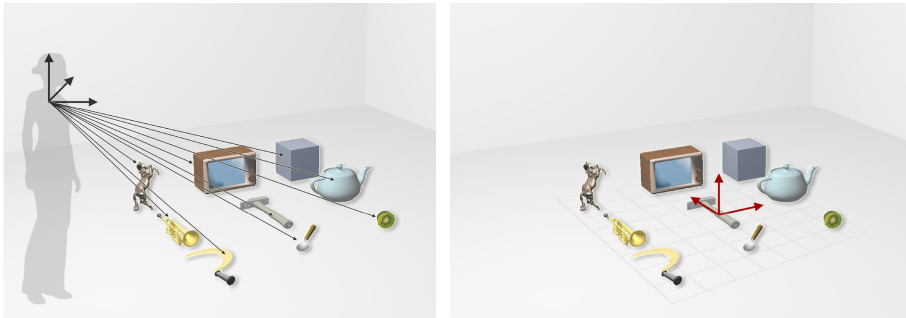

Fig. 1. Visualizations of egocentric (left) and allocentric (right) coordinate representations. In an egocentric coordinate system locations are represented relative to the body-orientation of a navigator as indicated by arrows. An allocentric coordinate system indicated by arrows and a grid represents locations as coordinates in a system centered on entities other than a navigator, such as an object array and/or the surrounding room.

locations (i.e., allocentric relations) are not directly represented, but can be derived from this representation. Egocentric coordinates can be stored in long term memory. When representing egocentric coordinates in working memory they have to be constantly updated during movements ([37]).

2.2 Allocentric Representations

2.2.1 Allocentric Coordinates

According to Klatzky ([20]), an allocentric coordinate system is located and oriented on an object or a location other than the navigator (Fig.1 right side). Stationary objects do not change their coordinates or bearings when the navigator (i.e., the representing system) is moving. Distance, direction and bearing of an object relative to the origin of the coordinate system are directly represented. Relations between two objects or locations other than the origin have to be derived. However, this is often assumed as computationally easy. The origin of an allocentric coordinate system has also been proposed as arbitrary or virtual ([13]). Please note that a pair-wise relation between two objects or locations is equivalent with the origin of a coordinate system centered on one of the two objects.

2.2.2 Perspective-Free Representations

An alternative interpretation of allocentric is non-centered. However, a coordinate representation is always centered, as the coordinate system has to have a defined origin with an orientation – even if the importance of this origin is de-emphasized. Structural descriptions offer a way to describe spatial relations in a non-centered way. For example, one can list all pair-wise distances between locations. Also the following constraints provide a structural description: distance(A,B) = distance(B,C) = 5 meters; angle(ABC) = 90°. If not given directly in the description, all relations have to be derived from the representation. Structural descriptions often have multiple solutions ([13]). Please note that many descriptions are perspective dependent and thus better described by egocentric or allocentric coordinates (e.g., “the trumpet is left of the hammer, the hammer is left of the teapot”).

2.3 The Encoding and the Retrieval of Elementary Spatial Representations

In the Introduction we summarized evidence for egocentric and allocentric coordinate representations. These and other spatial representations have to be formed from perception and are used for action. In the following we will present theoretic considerations of how these processes can be explicated along with empirical evidence for the presented conceptualization.

2.3.1 Deriving Egocentric (Trunk-)Coordinates from Lower-Level Representations

Our perceptions are relative to our own position, or even – more detailed – relative to the locations of parts of our body (e.g., relative to the positions of our hand, our head or our retina). All these representations are often called egocentric.[2] An egocentric trunk-based representation is derived from peripheral reference frames. Imagine using your hand for searching a table with closed eyes until you touch the object. By knowing where your hand is relative to your trunk you can derive the egocentric (trunk) position of the touched object. The visual identification of object locations works similarly. The location of an object on the retinas (i.e., in retinotropic coordinates) is transformed into head coordinates and then to egocentric trunk coordinates. Neurophsiological studies show that egocentric coordinate systems exist in the posterior parietal cortex ([1], [12]). Behavioral experiments indicate that head and trunk-based reference frames can be stored in memory ([50]). From the theoretical side, Grush ([13]) showed how a coordinate structure can be derived from lower level coupled sensory and action channels by a process he called s-coordination. This provides a model of how coordinate systems could be derived from a perception-action format as found in sensorimotor contingencies.

2.3.2 Deriving Allocentric Coordinates from Lower-Level Representations

Allocentric coordinates have to be derived from egocentric ones, just as egocentric coordinates are derived from data in a perception-action format. Deriving allocentric coordinates directly from a perception-action format would at least implicitly encompass egocentric relations. Byrne, Baker, and Burgess ([6]) suggested that such a transformation starts with egocentric coordinates in posterior parietal cortex, involves retrosplenial cortex, head-direction cells in the Papez circuit ([41]), and finally result in allocentric coordinates in the hippocampus (see also [11]). In hippocampal place cells a navigator’s location is represented relative to the immediate surrounding area ([31]). The navigator seems to be the only “object” represented within such an allocentric representation.

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[2] As these representations are merely body-centered they cannot be classified as true egocentric representations in Campbell’s sense (see 2.1.1). Please note that retinal, head or torso-based coordinate systems each refer to one reference point (i.e., the retina, or the head, etc.) and thus are elementary spatial representations.

From a cognitive point of view, several solutions to the problem of transforming egocentric into allocentric coordinates are possible. One possibility is to mentally shift the perspective from which an environment is encoded to a non-ego position. The non-ego position works as the origin of a coordinate system relative to which locations are encoded. As this position was not (physically) encountered, the resulting coordinate system is an allocentric one. Humans are shown to be capable of using such a non-ego position ([26]).

Another possibility is to derive the allocentric relations directly from the egocentric coordinates. When wanting to cross a street with heavy traffic, one can represent the car locations by egocentric vectors. The allocentric relation ‘the red car is in front of the silver car’ can be computed from the egocentric representation. This representation can be in a natural language format as the example sentence or in a format closer to perception. In this way coordinate systems relative to any structure (objects, rooms, etc.) in the egocentrically represented environment can be derived.

Alternatively to an allocentric coordinate system also a perspective-free representation might be formed from egocentric representations. This would be a structural description of the environment (see 2.2.2). A perspective-independent behavior could also be obtained when assuming that the coordinate origin – especially its orientation – does not exhibit large computational and thus behavioral consequences. However, most studies do find performance differences which can be explained by the orientation of allocentric coordinate systems respectively relations. This indicates that the orientation of an allocentric reference frame does play a role ([23], [49]). Consequently, perspective-free representations are allocentric representations which only exist in addition to allocentric coordinate representations whose orientation matters.

The last sections examined how allocentric representations and egocentric coordinate representations can be formed from lower level representations and discussed empirical evidence for it. The next section is concerned with how such representations are retrieved and used for action.

2.3.3 Retrieving Elementary Spatial Representations

If egocentric and allocentric representations are to guide action, they have to be transformed into a sensorimotor format. Inverting the construction process of such representations is a potential model for how this might work. The coordinate system representing spatial relations in memory has to be transformed into the “current” egocentric coordinate systems of the navigator and from there into a perception-action format to elicit behavior. The former transformation is not required when all relevant information was updated or an egocentric long-term memory representation from the same viewpoint can be accessed. A differently oriented egocentric or any allocentric memory requires a coordinate transformation into the current egocentric orientation. Egocentric long-term representations from cleverly chosen view-points can thus minimize the transformations required during retrieval. For example, decision points in route navigation might be represented in this way ([25]). Structural descriptions also have to be transformed e.g., by building a mental model of the description (cf., [17], [18]).

Indeed, the described coordinate transformations can be shown to occur in alignment experiments. An alignment between a navigator’s current orientation in a physical or imagined environment and the orientation of the egocentric or allocentric memory representation of this environment yields better performance than if the current body orientation and the memory orientation are misaligned ([9], [26], [37]). For allocentric representations, orthogonal misalignments seem to be less detrimental than oblique misalignments ([19], [26]).

When elementary spatial representations are used for guiding behavior, it must be clear which representation is guiding behavior at a certain time. This is unproblematic for representations of different locations: Only the representation of the environment crucial for the task at hand is used and not a representation of the distal environment. If during encoding only one kind of representation (egocentric or allocentric) is formed due to the circumstances, this is not problematic either. Only the existing representation guides behavior. However, it has been shown that participants can encode egocentric and allocentric representations of one and the same environment and use them depending on the task requirements ([43], [53]). Task specifications must thus select the appropriate representation. Alternatively, egocentric and allocentric representations could be combined. This, however, results in a non-elementary representation and will thus be discussed in section 3.

As shown so far, there is evidence for elementary spatial representations; their construction and usage can be made plausible both theoretically and empirically. However, not all situations can be captured successfully by elementary spatial representations.

2.4 Limitations of Elementary Representations

Explaining behavior by elementary spatial representations alone poses some difficulties for representing larger spaces as well as for representing objects, snapshots and some scenes.

2.4.1 Representing Larger Spaces

Representing environmental spaces such as cities or buildings with elementary representations only poses some specific problems. As more and more locations are encountered, representing them within a single representation will require bigger and bigger representations. For example, if all locations within a city would have to be represented within a single egocentric or allocentric representation, representations with an enormous amount of information would have to be dealt with. From a computational point of view our mental resources seem too limited to represent a city within a single coordinate system which would have to be accessed as a whole. Thus, substructures have to be formed which are not elementary representations in the sense used here. Alternatively, we could form multiple representations of local surroundings (e.g., each street) and use these representations when dealing with this street. Then, however, these local representations are unconnected. Elementary representations do not provide means of how to represent relations between multiple representations. It seems impossible to find a route to a goal or to point there based on unconnected local representations. In principle, this problem already occurs for visible spaces. Representing the location of each cobblestone by a single vector or by an allocentric coordinate requires very large memory. It seems reasonable to cluster locations together e.g., to form a floor, wall or house. However, such clustering requires an extension of the so far described elementary representations.

2.4.2 Situations Which Require Egocentric and Allocentric Relations to Represent Them

Some examples are difficult to confirm to elementary representations, because they seem to rely on allocentric as well as egocentric relations at the same time. Pictorial snapshots are often considered typical examples for egocentric representations ([52]). However, probably only very few people would conceptualize a snapshot as vectors pointing to each pixel of the snapshot. The snapshot surely is represented from a certain perspective; however, the pixels are also represented relative to the picture frame, which is an allocentric relation. The same applies to the memory of a (paper) map. Relations between locations on this map are memorized (i.e., allocentric relations). However, the map is also encoded in the orientation it was perceived which is an egocentric relation ([42]). This egocentricity cannot be captured by just declaring the whole memory as allocentric, because the reference point (i.e., the origin of the allocentric coordinate system) is unclear. Is it the border of the snapshot or map or is it the observer? Both have to be taken into account which is not possible within a single elementary representation. Broadening the definition of egocentric to all representations taken from an experienced location is not a good solution either. Then egocentric representations would also encompass object-to-object relations and the egocentric-allocentric distinctions would be reduced to representing an environment from an experienced or not experienced viewpoint.

Also object parts are represented relative to an object based reference frame which is an allocentric relation. For example, we surely do not represent mere egocentric vectors to object parts and update them individually. We do not err about how object parts relate to each other, even after disorientation. Despite this, objects seem to be encoded from experienced views ([3]). To explain this, an additional reference has to be taken into account – namely the observer. This is an egocentric relation. Consequently, also the representation of objects requires egocentric and allocentric relations together. In terms of object processing, both view-dependent and structural elements have to be considered ([14]).

A last example is the verbal statement “the target is left of the tree”. This statement involves three locations: of the speaker, the target and the tree. Similarly to the examples above this situation cannot be sufficiently captured by egocentric vectors only. The relation between target and tree is one between two non-egocentric locations, therefore, an allocentric relation. On the other hand, the situation can neither be conceptualized in a mere allocentric way. As the tree does not offer any directional cues by itself, the direction of the target relative to the tree (i.e., left of) is derived from the perspective of the speaker which is an egocentric relation. Again, egocentric and allocentric elements seem to be combined.

We propose that solutions to the mentioned problems require combining elementary spatial representations into complex representations. In the following chapter we will propose three ways of how such complex spatial representations can be conceptualized.

3 Complex Spatial Representations

All four elementary representations can be extended to represent further locations by simply adding more locations within the representation. As indicated in the last section this does not seem sufficient to explain all spatial behavior. The allocentric and the egocentric coordinate representations (2.1.2 and 2.2.1) can also be combined with each other in a hierarchical way or by pair-wise relations forming a complex representation.

3.1 Pair-Wise Relations

A pair-wise relation between two coordinate systems specifies the direction and distance necessary to get from coordinate system 1 to coordinate system 2 as well as the angle between the orientations of the two systems. In mathematical terms this is a matrix multiplication. In psychological terms this corresponds to a perspective shift. Due to the equivalence of a pair-wise relation and a coordinate representation, a pair-wise relation can be instantiated by considering the origin of coordinate system 2 as a position (location plus orientation) within coordinate system 1. As this can work the opposite direction at the same time, both coordinate systems are not related in a hierarchical fashion, but are on the same level. Pair-wise relations could occur between egocentric, allocentric and combined ego- and allocentric coordinate systems. Pair-wise relations can avoid the problem of representing many locations, as only one coordinate system or a subset can be selected and used for orientation in working memory. This selection is possible as complex spatial representations are compositional (i.e., they are combined out of elementary spatial representations). Still, the granularity of the spatial representation does matter. Pair-wise relations between representations of vista spaces such as streets or rooms do seem plausible ([24]). However, connecting all objects within a city or a building by pair-wise relations requires many relations to be encoded. This does not seem very practical from a computational point of view. A limitation to represent only relations to neighbors can solve this problem. Hierarchical representations provide an alternative solution.

3.2 Hierarchical Relations

3.2.1 Allocentric Hierarchy

Hierarchical conceptions of spatial memory are popular ([15], [23], [39]). In this specific conception lower level coordinate systems (ego- or allocentric) are integrated within a top-level allocentric coordinate system (Fig. 2 left side). The area of the lower level coordinate system is thus part of the area represented by the higher level coordinate system. This is not necessarily the case for pair-wise relations. A top-level coordinate system could correspond, for example, to a city whereas lower level coordinate systems could represent single streets within this city in more detail. Or the top-level coordinate system corresponds to a room and the lower level one to objects within this room. The lower level coordinate systems are not necessarily allocentric, but could be egocentric as well.

A specific example for such an allocentric-egocentric combination is the position of a navigator (i.e., an egocentric coordinate system) within an allocentric map ([6], [36]). In such a representation the position of the navigator relative to an environment is constantly updated during movement. A potential problem of such an updating is the choice of the relevant hierarchy level relative to which the egocentric coordinate systems should be updated. How does one decide if it is relative to the city, the district or the street level, or relative to all levels at the same time? In addition, what happens when moving from one street to the next one (which is covered in detail by another representation)? This would have to be specified in more detail.

Survey and route knowledge can also be conceptualized within one allocentric hierarchy (see also [34]). Pair-wise relations between lower level coordinate systems represent route knowledge (i.e., knowing in which direction the next reference frame is located). These lower level coordinate systems are embedded within a higher-level allocentric coordinate system within which the relative spatial locations between distant lower-level coordinate systems are specified.

Elements in a hierarchy might also be linked to non-spatial information (see also [22]). For example, labels such as "city hall", "downtown", or "Tübingen" can be attached to one or multiple coordinate systems ([24]). These labels can relate to general background knowledge about the world.

Hierarchical relations between coordinate systems easily avoid the problem of large spaces. Only the hierarchical level necessary for the task at hand has to be accessed thus avoiding too large data sets to be processed.

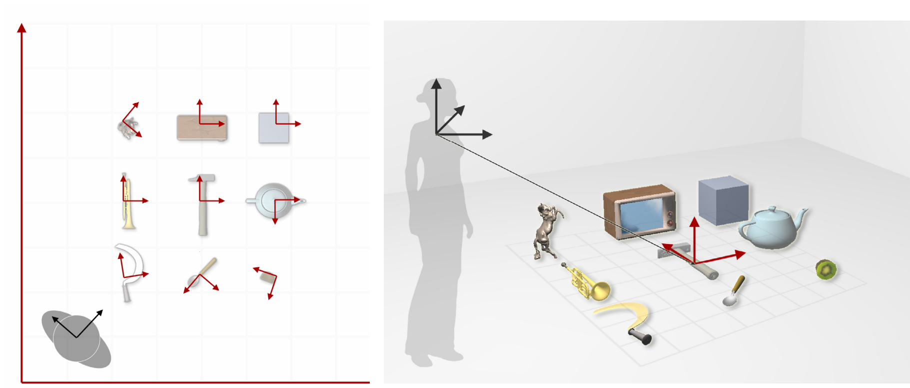

Fig. 2. Visualizations of hierarchical spatial representations. In an allocentric hierarchy (left side) the top level allocentric reference frame (long arrows and grid) defines lower level allocentric (here for each object) or egocentric (the navigator) reference frames. In an egocentric hierarchy (right side) lower level reference frames (e.g., for a room, an object array as shown here, or for individual objects) are subsumed under a top-level egocentric reference frame.

3.2.2 Egocentric Hierarchy

In this conception, lower level egocentric or allocentric coordinate systems are subsumed under a top-level egocentric reference frame (Fig. 2 right side). For example, an allocentric reference frame of an object is subsumed under an egocentric one. The object is represented from a certain perspective; however, also the allocentric relations between object parts are represented. Such a representation captures view-dependent and structural elements which both have been shown to contribute to object recognition ([14]). Similarly, the double nature of memorized views or maps can be captured. Locations on the snapshot or map are represented allocentrically relative to the map or snapshot frame. This frame is part of an egocentric representation capturing the perspective element. In the tree example, the allocentric coordinate system of the tree inherits its orientation from the higher level egocentric one thus specifying the relation left of the tree. Please note that also allocentric hierarchies are technically capable of solving this problem. The object, view, map or target-tree line defines the top-level allocentric coordinate system and the observer is subsumed as a lower-level egocentric system. Intuitively, this might not seem to capture the situations adequately, but from a formal point of view it is sufficient.

The problem of representing large spaces is solved via the hierarchical structure of the representation just as in the case of allocentric hierarchy. The character of the top-level reference frame is irrelevant for this; it is the hierarchical structure which is crucial. However, the hierarchical embedding under an egocentric top-level reference frame has the advantage that "large-scale" behavior (navigation) can be triggered directly by the egocentric top-level representation without costly transformations. If needed, however, detail information can be retrieved from embedded allocentric (or egocentric) representations and used – after transformation – as an additional source for guidance.

Updating an egocentric hierarchy during movements does not cause the same reference problems as in the case of allocentric hierarchy. A limited working memory buffer keeping a few objects could be updated. New visual input would overwrite existing objects (i.e., updated coordinate systems) unless rehearsal processes such as attention shift protect them.

Also route and survey knowledge can be conceptualized within an egocentric hierarchy. Route knowledge may be represented by pair-wise related coordinate systems just as in an allocentric hierarchy. This long-term knowledge might then be accessed from a currently active top-level egocentric reference frame and navigational instruction be derived. Rather than representing survey relations explicitly within a higher-level allocentric coordinate system, they can be derived online from the long-term representation. This can be achieved by integrating the pair-wise relations between coordinate systems along a route to a target within the currently active egocentric top-level coordinate system (for details see [24]).

The conscious perception of our surrounding world can also be conceptualized within an ego-allocentric hierarchy: an egocentric stage containing allocentric elements such as the form of the room or objects within ([45]). Attention might be focused on elements in this hierarchy either top-level or specific lower level coordinate frames ([21]) emphasizing egocentric or allocentric relations. All examples of egocentric hierarchies mentioned so far spanning from objects, snapshots, and maps, via object constellations and routes to survey relations can be consciously experienced or imagined. It can thus be conjectured that egocentric hierarchies might best capture our perspectival conscious experience of space.

Plausible brain areas corresponding to an egocentric hierarchy encompass posterior parietal cortex and the parahippocampal place area. As mentioned earlier, egocentric short term representations of a real or imagined current surrounding can be found in posterior parietal cortex ([2], [7], [12]). However, also neurons responding to allocentric relations have been observed ([38]). Although their interrelation was not specified, it is plausible to assume that they are linked in the sense of an egocentric hierarchy. Longer-term memory representations of an egocentric hierarchy for scenes seem to be found in the parahippocampal place area ([10], [11]). This area is more active when showing pictures of rooms or room parts (i.e., walls, floor, etc) in their correct arrangement than when scrambling the order of the room parts and thus destroying their allocentric relations ([10]). In addition, these representations are viewpoint dependent and, thus, sensitive to egocentric and allocentric aspects ([11]). Here again an egocentric hierarchy is plausible.

Complex spatial representations are capable of representing situations difficult to explain by elementary spatial representations only. Especially hierarchical solutions seems plausible from an empirical, a phenomenal as well as from a computational perspective.

4 Conclusions

Starting with the seminal work of Klatzky ([20]) many studies examined the application of egocentric and allocentric reference frames. The clear definition of these terms allowed for experiments distinguishing between these terms. In the present paper we compared the original definition of Klatzky with two alternative conceptions (i.e., sensorimotor contingencies and perspective-free representations) and discussed their encoding and retrieval for navigation. Although, the spatial cognition community has gained a lot of insights into when and how humans apply egocentric and allocentric references, not all phenomena can be captured with elementary conceptions of egocentric and allocentric representations. Especially two situations seem problematic: the representation of a large number of locations and representing objects and situations which seem to encompass egocentric and allocentric relations at the same time. In order to solve these problems, we propose complex spatial representations which are constructed from egocentric and allocentric coordinate systems. They can take multiple reference points into account and their compositionality is suited for a short-term memory of limited capacity. From our point of view, especially hierarchical conceptions and here especially hierarchies with a top-level egocentric coordinate system seem promising for representing also complex spatial situations. The discussion in the last years was shaped by a clear-cut distinction between egocentric and allocentric reference frames as separate systems of representation. We think that future research should not emphasize the separation of these representations, but rather their interaction.

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