Action related determinants of spatial coding in perception and memory

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Abstract. Cognitive representations of spatial layouts are known to be affected by spatial as well as nonspatial characteristics of the stimulus configuration. We review findings from our lab suggesting that at least part of the effects of nonspatial factors originate already in perception and, hence, reflect principles of perceptual rather than memory organization. Moreover, we present evidence that action-related factors can also affect the organization of spatial information in perception and memory. A theoretical account of these effects is proposed, which assumes that cognitive object representations integrate spatial and nonspatial stimulus information as well as information about object-related actions.

Introduction

Our environment consists of objects and relations between objects. However, the term 'object' is relative in multiple respect. Most objects consist of more than one level and each level might have its own object character. For example, cities consist of houses and streets, houses consist of rooms, rooms of ceiling, floor and walls etc. What might reasonably be termed 'object' from a certain perspective might just as reasonable be termed element of an object or group of objects from another. Accordingly, spatial relations can be of global or local nature, depending on the context and point of view: A given room can be to the left or right of another room in the same house, to a house in the same street, to a street in the same city, and so forth.

Human perception, cognition, and action can be directed to objects as defined on any of these different levels, which raises the question of how spatial layouts are represented in the human cognitive system. To approach this issue, several authors have proposed that complex perceptual structures are represented in a hierarchical fashion (see, e.g., McNamara, Hardy, & Hirtle, 1989; Navon, 1977; Palmer, 1977). The main assumption is that object representations, which themselves might already be the result of a cognitive clustering of subordinate objects and features, are combined into object clusters with a certain spatial intra-object structure on a superordinate level (Palmer, 1977; Watt, 1988).

The idea of hierarchical representation or, more liberally, of cognitive object clusters raises the question after the criteria according to which perceptual and memory information about spatial layouts is structured and organized. In this article, we focus on two types of criteria. On the one hand, exogenous factors, such as similarities between the color and shape of objects, may suggest the integration of similar objects into a common cognitive group or category. On the other hand, we will argue that endogenous factors, such as knowledge about nonperceivable characteristics of objects or the actions they afford, may also contribute to the cognitive organization of object information. Indeed, as we will discuss in turn, there is evidence for the impact of both exogenous endogenous factors on the cognitive clustering of spatial layouts.

The impact of exogenous factors on spatial coding: Color and shape

In the literature, there are several indications that spatial memories are influenced by nonspatial attributes of, or relations between, the respective objects, such as linguistic (Bower, Karlin, & Dueck, 1975; Daniel, 1972), semantic or episodic (Hirtle, & Mascolo, 1986; McNamara & LeSueur, 1989; Sadalla, Staplin, & Burroughs, 1979), and functional (McNamara, Halpin, & Hardy, 1992) information. For example, McNamara, Ratcliff, and McKoon (1984) observed that estimations of distances between cities on a learned map did not only depend on the Euclidian distance, but also on road distance—that is, on whether the to-be judged cities were directly connected by a road or not. These findings suggest that nonspatial information is automatically encoded and integrated into, or together with, spatial representations to a degree that sometimes even alters or distorts the original information in systematic ways (for an overview see McNamara, 1991; Tversky, 1981). Such findings have been taken to question the possibility that an adequate model of a spatial representation can be built around a strictly Euclidean conception (e.g., Hirtle & Jonides, 1985; McNamara et al., 1984). As an alternative model, several authors have therefore proposed that spatial areas are arranged hierarchically, so that judgements across clusters require knowledge of spatial arrangements within each cluster plus knowledge of the spatial arrangement of the superordinate structures (e.g., McNamara, 1986; Stevens & Coupe, 1978).

What kind of processes might be responsible for such kind of cognitive organization? Obvious candidates are memory processes which may aim at reducing the perceptual input to minimize storage costs and optimize later retrieval–an idea that is implicit or explicit in most studies on distortions of spatial memories (e.g., Tversky, 1981). However, hierarchical coding could also be a result of perceptual processes, which may not passively register sensory evidence but actively integrate the available information into a structured whole or Gestalt (Baylis & Driver, 1993; Navon, 1977). If so, the distortions and clustering effects observed so far in memory tasks may not so much reflect organizational principles of memory processes, but rather be a more or less direct consequence of distortions and clustering tendencies in perception.

--- insert Figure 1 about here ---

In a recent series of experiments, we found support for a perceptual interpretation of clustering effects in spatial memory (Gehrke & Hommel, 1998; Hommel, Knuf & Gehrke, 1999a). We presented our subjects with visual map-like configurations of up to 18 objects, which looked like houses of an imaginary city (see Figure 1). Color or shape served as exogenous factor, that was assumed to induce cognitive clustering. That is, either the coloring or the shape of the objects was chosen in such a way that the configuration could be subdivided into three or four perceptual clusters (e.g., houses at locations B, C, D, and F were red, houses at locations E, H, I, and L green, etc.). To test if color and shape affected the coding of the spatial information between the objects, participants were asked to perform two spatial tasks, an unspeeded estimation of Euclidean distances — a common measure in memory experiments — and the speeded verification of sentences describing spatial relations (e.g., "is house A above house B?") — a task often used in perceptual experiments. Participants performed under three conditions in three consecutive sessions: In a *perceptual* session, the configuration was constantly visible; in a *memory* session, participants first memorized the configuration and then performed the task without seeing it; and in a final *perceptual/memory* session, the configuration was again visible, so that both perceptual and memory information was available.

As expected, the time it took to verify the spatial relation between the members of a pair was shorter when both members shared a perceptual feature and, hence, belonged to the same "perceptual group" (e.g., relation E-L was judged faster than C-I). Interestingly, this was true for all three sessions, which indicates that memory processes were unlikely to be responsible. Apparently, the spatial layout was coded in a way that led to the integration of information about perceptually similar objects into common cognitive clusters, so that later access to information about objects belonging to the same cluster was easier.

Surprisingly, distance estimations were not affected at all by the feature-overlap manipulation. On the one hand, this may have been due to a lower sensitivity of estimation measures as compared to reaction time measures–a theoretically uninteresting possibility. On the other hand, it is conceivable that these two measures tap into different processes. For instance, it may be that reaction time measures are sensitive to the cognitive organization of spatial (and nonspatial) information whereas estimation measures are sensitive to the quality of spatial information, such as with memory distortions (see McNamara, 1991, for a broader discussion of this issue). If so, our findings might indicate that nonspatial factors do not really alter the quality of spatial memories, although they can affect the way knowledge about spatial relations is organized and the likelihood that these relations are encoded (see McNamara & LeSueur, 1989). At this point, the available evidence does not allow us to distinguish between these alternative interpretations; yet, it is interesting to note that evidence of cognitive clustering can be obtained in the absence of qualitative distortions and, hence the two measures (if not the processes they measure) can be dissociated. At any rate, we consistently obtained strong effects of exogenous variables on reaction times, which is the measure we will focus on in the following.

The coding of perceptual events and action plans

The findings reported so far suggest that objects forming a spatial array are cognitively represented by clusters of object codes that facilitate intra- as compared to inter-cluster processing. In our previous studies, we used exogeneous factors to induce cognitive clustering, that is, manipulations of perceptual object features. Before we go on to discuss evidence of the impact of endogeneous, action-related factors on spatial coding, it is instructive to consider how cognitive clustering might be work in detail.

--- insert Figure 2 about here ---

According to the *Theory of Event Coding* (TEC) proposed by Hommel, Müsseler, Aschersleben, and Prinz (1999), perceived objects are cognitively coded in two steps. First, the features of the respective object are registered and the corresponding feature codes activated. Second, the distributed feature codes are integrated into a coherent event representation. Figure 2A sketches how this might work in tasks like those employed by

Hommel and colleagues (Gehrke & Hommel, 1998; Hommel et al., 1999a)[1]. Assume an array consisting of three equally-spaced objects is presented, say, three huts named DUS, FAY, and MOB, from left to right, with DUS and FAY appearing in red and MOB in green. Let us further assume that the task is to verify statements regarding the relative horizontal location, such as "is DUS left from FAY?" (yes/no). To solve such a task, especially when the display is no longer visible, requires the integration of at least two features or attributes: the name and the (absolute or relative) location of each object. However, if these two features would be the only ones involved, it would be hard to understand why the verification performance of our subjects was affected by color and form manipulations. Therefore, it seems reasonable to assume that color and form, as well as other features of the objects, also became a part of the object representations, just as depicted in Figure 2A.

If so, the representations of DUS and FAY would be associated through the use of the same color code (red), and all three representations would be associated through a common form code (hut). Consider, for instance, what happens when the retrieval cue "DUS" is presented (as in the question "is DUS left from FAY?"). This cue would access the object representation of DUS, so that the corresponding spatial location can be determined. However, given that the codes "red" and "hut" are part of this representation, activation is spread to the other object representations with which those codes are shared. This means that accessing the representation of DUS also leads to a strong activation of the representation of FAY (via both color and form links) and to a weaker activation of the representation of MOB (via the form link only). Accordingly, if then the representation of FAY is accessed, it is already primed, which facilitates the retrieval of (e.g., spatial) information from this

[1] At this point, our findings do not necessarily require the assumption of different representational levels or hierarchical coding, which is why we chose to present a nonhierarchical account. This is not to deny that more complex spatial arrays or maps can be or actually are coded in a hierarchical fashion, and it would be easy to incooperate hierarchies into a TEC-type model. However, our main point here is that nonspatial information is integrated into object representations, and that this

representation as compared to retrieval from the less strongly primed representation of MOB. Hence the better performance with greater feature overlap.

--- insert Figure 3 about here ---

A further interesting assumption of TEC and the related *Action-Concept Model* (ACM) of Hommel (1997, 1998) is that perceived and produced events (i.e., "perceptions" and "actions") are cognitively coded in the same way, namely in terms of the perceivable features they produce. The key idea is that actions are performed to produce perceivable outcomes—action effects. However, this means that the actor has to have acquired some knowledge about which action is likely to produce which outcome. How it is acquired is sketched in Figure 3. First, a motor pattern *m* is activated (intentionally or unintentionally), which leads to some kind of movement, that again produces perceivable action effects. For instance, pressing a particular key of the left side of one's body will be represented by codes referring to the spatial and nonspatial features of the key being pressed (including possible further consequences of keypressing, such as the consequent launch of a rocket) and the finger pressing it, as delivered through the available sensory channels. These effects are perceived and internally coded through the activation of codes representing the features of the action effects, say, codes e_1, e_2, and e_3. As the activation of *m* and e_1, e_2, and e_3 will overlap in time—a situation that is known to support learning—they will become associated, thus forming what Hommel (1997) called an *action concept*. Action concepts can be assumed to represent the building blocks of intentional action, because they provide the necessary precondition for goal-directed action planning: Once motor patterns and outcome

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effectively links the representations sharing some of this information—an issue that we feel is independent from the hierarchy issue.

representations are associated, activating the intended action effect is sufficient to select and implement the required motor pattern.

An important implication of this view on the cognitive representation of action is that there might be no qualitative difference between feature codes representing perceived events and feature codes representing actions or action plans. If so, there is no reason why codes of object-related actions should not become part of object representations, which in the present context offers an interesting hypothesis. Assume that our three huts DUS, FAY, and MOB all have the same form and color, as sketched in Figure 2B. However, whereas DUS and FAY are associated with some action X, MOB is associated with another action Y. If actions are represented in terms of their features, this situation should be very similar to that with the green and the two red huts, in that the representations of DUS and FAY are more strongly connected with each other through the common use of Action X features (whatever these may be) than with the representation of MOB. Accordingly, spatial relations between DUS and FAY should be easier to judge than, say, between FAY and MOB. Whether this is so, we attempted to find out in another series of experiments, which we will now review.

The impact of endogenous factors on spatial coding: Simple and complex action

The TEC framework offers a number of arguments why endogenous, action-related factors might play a similar important role in spatial coding as has been shown for exogenous factors. Obviously, we should be able to test this hypothesis with the same experimental technique and under comparable conditions as for the exogenous studies, which is what we did (Hommel, Knuf, & Gehrke, 1999b). The spatial arrangement of the stimulus configuration was the same as before (see Figure 1), only that a homogenous stimulus set was used (black on white drawings of 18 identically shaped houses).

In a first session, subjects were to perform simple keypressing actions "towards" particular houses. In each trial, one of the houses would flash and the subject would press one of three or four response keys. The mapping of keys upon house locations followed the same logic as in our exogeneous studies. For instance, one key was to be pressed in response to locations B, C, D, and F, another key in response to locations E, H, I, and L, and so forth. The mapping was fixed but not communicated to the participants, so that they had to find out the correct mapping by trial and error. Once they produced correct consecutive responses to all locations this first mapping-acquisition phase ended. The remaining sessions were as in the exogenous studies, that is, the first was a *perceptual* session with the configuration being visible, a *memory* session with judgments based on the memorized configuration, and a final *perceptual/memory* session, where the configuration was again visible. Although we sometimes also collected distance estimations (which again produced only null effects), our main measure was reaction time for the verification of spatial relationships.

In a first experiment, the location-response mapping had no effect, that is, pairs mapped onto the same response were not judged faster than other pairs. However, there was some indication of an effect in the first, perceptual session but not in the following sessions. One reason for that may be the decay of mapping information. As the perceptual session immediately followed the mapping-acquisition phase, the location-response associations must have been more activated than in the following sessions, which took place one or more days later. Consequently, we (i.e., Hommel et al., 1999b) conducted a replication, where the subjects were to perform the keypressing task in the beginning of both the perceptual and the following memory session, so that the location-response associations were to be reactivated. As expected, this produced a substantial mapping effect: Verification times were faster for pairs mapped onto the same response (e.g., E-L) than for pairs mapped onto different responses (e.g., C-I). Obviously, then, response-related information was integrated into the representations of our visual objects. Consequently, accessing those representations in order to extract spatial information for the verification task reactivated codes related to the associated response key, which again must have primed representations associated with the same response.

It is conceivable, that this effect is restricted to the very simple, spatial responses we employed. In the cognitive system, the keypressing responses might have been coded as just another set of locations used in the wider context of the verification task. That is, house locations and response locations might have been coded in a very similar way and on the same feature dimensions, which might have facilitated the integration of stimulus and response information. Although this would not make the demonstration of such an integration less interesting, it would certainly restrict the degree to which our findings can be generalized. Another, theoretically perhaps even more interesting constraint may have to do with the semantic relationship between our stimuli and responses. Given that the responses were spatially defined, they can in some sense be understood as "directed toward" the associated houses or house locations (although the spatial stimulus-response mapping was balanced across subjects). It may well be that it was this kind of "semantic" relationship that induced the integration of response information into object representations.

To investigate the possible roles of dimensional overlap and of the semantic relationship between stimuli and responses, Hommel et al. (1999b) conducted a further experiment with more complex everyday actions. In one group of subjects, particular houses were associated with house-related activities that the subjects had to perform, such as coloring the picture of a house, constructing a small house with wooden building blocks, opening a door of a toy house, and operating a door knocker. Again, three to four houses were mapped onto a common activity. In another group of subjects, the activities were all unrelated to houses, such as reading aloud a weather report, tying a shoe, telling the time, and taking a sip of water.

Of course, all actions were extended in space (as any action is), but their main goal was clearly not spatially defined as was the case in our first action experiments. Thus, if actions would be integrated into object representations only if they are defined on the same (spatial) dimension as the objects, no integration should take place in this experiment, hence no mapping effect should be observed. However, if the crucial factor would be the semantic relationship between objects and actions, evidence for integration should be obtained with house-related activities but not with house-unrelated activities. Indeed, this is what the findings show. If the actions were house related, verification was faster with pairs mapped onto the same than to different activities, which was true in all sessions. In contrast, there was no effect of mapping in any session if the actions were unrelated to houses. This shows that the integration of action-related information into object representations is by no means restricted to simple, strictly spatially defined actions. However, integration is limited by some kind of relevance factor, that is, actions are integrated only if they have something to do with the object at hand.

Conclusion

The findings reported here add to the available evidence showing that the spatial coding of object arrays is affected by the nonspatial attributes of these objects. Apparently, information about the spatial characteristics of objects, or relations between objects, are not stored in a way that allows for a selective retrieval of this information. Instead, spatial and nonspatial object information is automatically integrated into a common object representation, so that later retrieval of one piece of information also reactivates the information associated with it (McNamara, 1991).

However, there are two novel points we wanted to make. First, in all our studies we consistently found the same effects under perceptual conditions, hence with judgments about visible displays, and memory conditions, where the relevant information had to be retrieved from memory. In fact, even the sizes of these effects were the same, leaving no room for some moderating factor. As pointed out by Gehrke and Hommel (1998) and Hommel et al. (1999a), this does not seem to fit with the often implicit but sometimes explicit (e.g., Tversky, 1981) idea that interactions between spatial and nonspatial codes reflect the organizational principles of memory processes. Rather, it seems that effects in memory tasks reflect the way the stored information has been organized in the process of perceptual encoding, and therefore, if anything, reflect organizational principles of perceptual processes. Yet, although this is an interesting, parsimonious, and provocative hypothesis that nicely accounts for the findings reported here, there are considerable methodological differences between the available studies on interactions between spatial and nonspatial information. Therefore, it would seem premature to generalize our own failure to find differences between perceptual and memory conditions before the possible differences between the experimental tasks used hitherto are explored somewhat more deeply.

Our second point is that spatial coding is not only affected by exogenous factors, such as stimulus features and contextual properties, but by internal, action-related factors as well. Apparently, people do not only group things that look the same, but also those things that afford similar actions. Apart from our action studies, such a conclusion is further suggested by observations of Merril and Baird (1987) and Carlson-Radvansky, Covey, and Lattanzi (in press). In the Merril and Baird study, students were asked to sort names of familiar local campus buildings. On the basis of a cluster analysis, two sorting criteria were identified: the spatial proximity between, and the functions of the buildings. As an instance of the latter criterion, all the dormitories, fraternities, and classrooms were sorted together. If one assumes that sorting behavior reflects the way the sorted items are organized in memory, the function of objects seems to provide at least one principle for this organization.

Carlson-Radvansky et al. (in press) instructed their subjects to place the picture of one object "above" or "below" a reference object. Among other things, the functional relatedness between the two objects was manipulated. Functional relatedness was high if, for example, a toothpaste tube was to be placed above or below a toothbrush, and it was low if a tube of oil paint was to be placed above or below a toothbrush. When the reference objects were presented in an asymmetrical fashion, such as with a lateral depiction of a toothbrush (i.e., with the bristles at one end of the brush), the horizontal placement was found to be biased towards the "functional parts" of the reference object. For instance, the toothpaste tube was not placed above or below the center of the toothbrush but closer to the bristles. Moreover, this bias was more pronounced with functionally related than with unrelated object pairs, hence, for the toothbrush example, stronger for the toothpaste tube than for tube of oil paint. Given that the functions of objects was not relevant for Carlson-Radvansky et al.'s task at all, this finding strongly suggests that functional, action-related information is an integrated ingredient of object representations.

Taken altogether, we feel that the implication of TEC or ACM that the cognitive representation of stimulus layouts might be enriched by action-related information or action affordances in the sense of Gibson (1979), is worthwhile to pursue. Indeed, if people are able to acquire and store spatial and nonspatial information about their environment, this ability should be first and foremost stand in the service of action planning and action control. After all, representing information without knowing what it is good for does not seem to be an overly useful strategy.

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Author Notes

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Figure Captions

Figure 1: Schematic representation of the spatial layout used by Hommel, Knuf & Gehrke (1999a). Each location was occupied by a house-like object, with the color and shape being systematically varied (see text).

Figure 2: A simplified model of the impact of nonspatial information on the verification of spatial propositions. ***A***. The red stimulus huts DUS and FAY, and the green hut MOB are cognitively represented by integrated object features referring to the object's name, location, color, and shape. Horizontal arrows indicate the use of common feature codes and the mutual priming produced by that. ***B***. The three huts are represented by codes referring to the name, location, and shape of the stimuli, as well as information about associated actions.

Figure 3: Schematic graph of the cognitive representation of action through action concepts, i.e., integrated structures of motor patterns, represented by *m*, and action-effect codes, represented by e_1, e_2, and e_3.

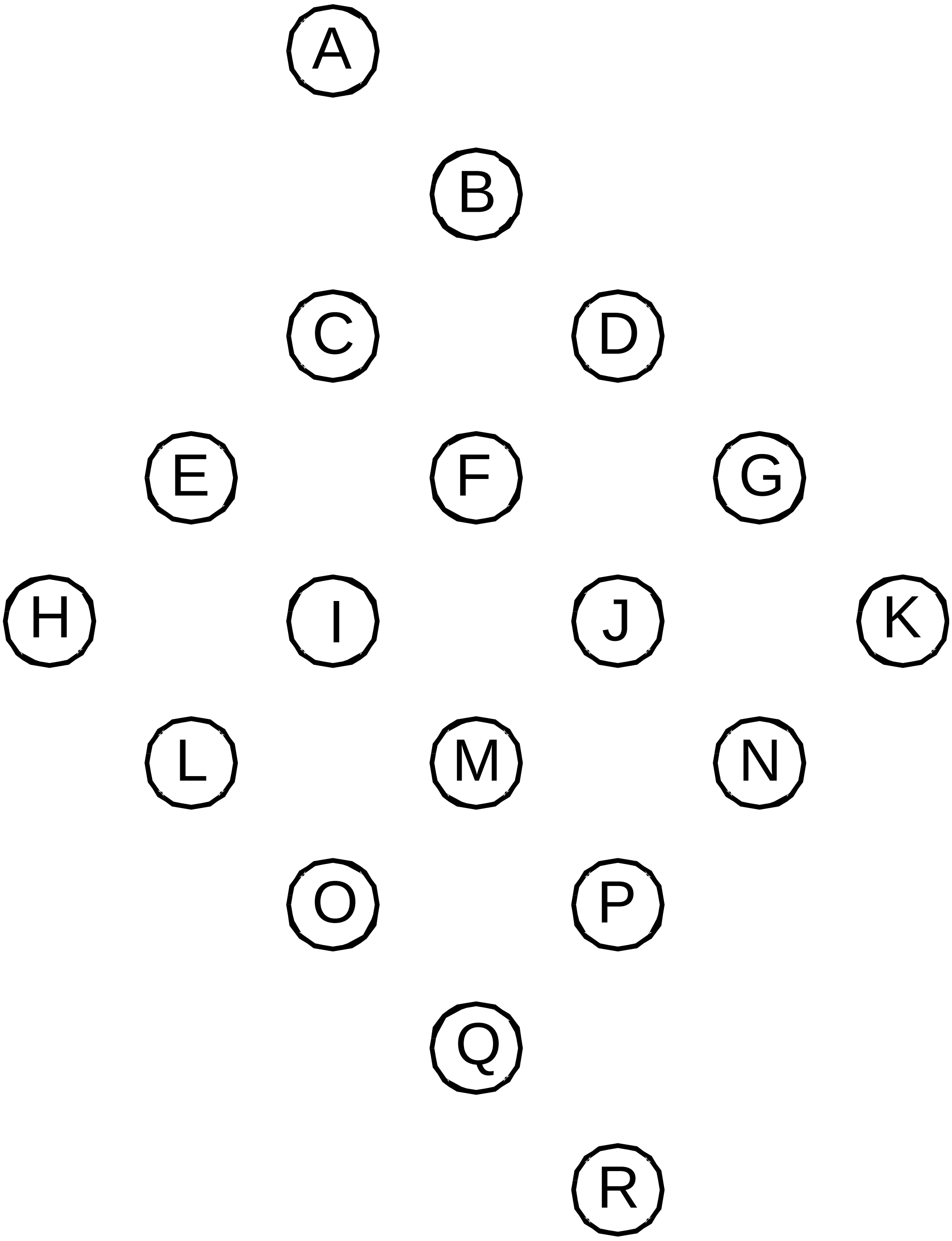

Fig. 1

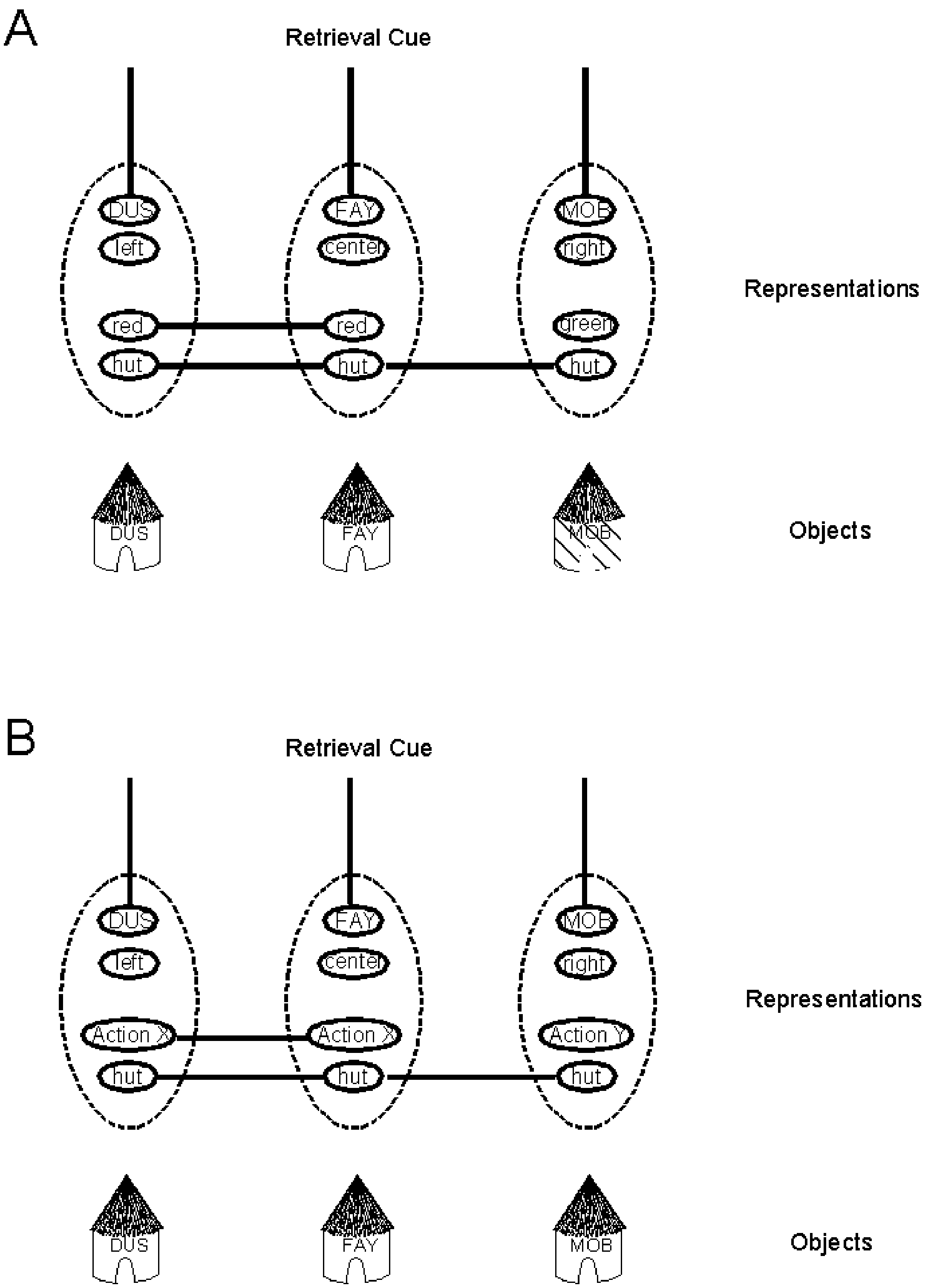
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Fig. 2

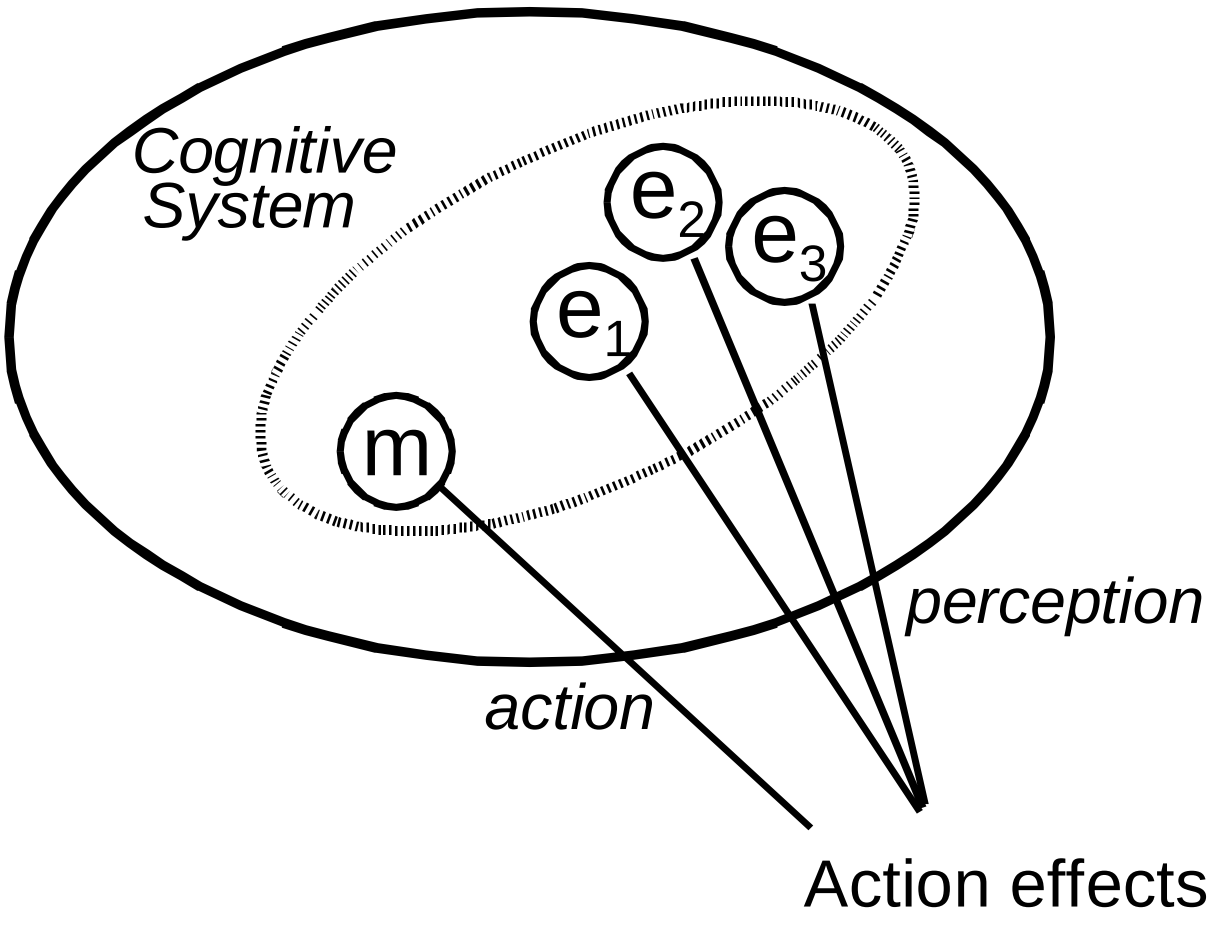
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Fig. 3