

## Opinion

## Self-Agency and Self-Ownership in Cognitive Mapping

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The concepts of agency of one's actions and ownership of one's experience have proved useful in relating body representations to bodily consciousness. Here we apply these concepts to cognitive maps. Agency is defined as 'the sense that I am the one who is generating the experience represented on a cognitive map', while ownership is defined as 'the sense that I am the one who is undergoing an experience, represented on a cognitive map'. The roles of agency and ownership are examined with respect to the transformation between egocentric and allocentric representations and the underlying neurocognitive and computational mechanisms; and within the neuropsychiatric domain, including Alzheimer's disease (AD) and other memory-related disorders, in which the senses of agency and ownership may be disrupted.

## Agency and Ownership in the Cognitive Sciences

Two decades ago, in an influential paper, the philosopher Shaun Gallagher distinguished between two important concepts: **self-agency** (see [Glossary](#)) and **self-ownership** (or, briefly, agency and ownership [1,2]). Agency is defined as 'the sense that I am the one who is causing or generating an action. For example, the sense that I am the one who is causing something to move, or that I am the one who is generating a certain thought in my stream of consciousness', while ownership is 'the sense that I am the one who is undergoing an experience. For example, the sense that my body is moving regardless of whether the movement is voluntary or involuntary' [1]. Together, these two highlight a substantial difference between a 'minimal-self' ('oneself as an immediate subject of experience, unextended in time'), and a 'narrative-self' ('self that is constituted with a past and a future') [1]. The minimal-self refers to the world mainly through the body: agency is expressed while moving one's body or body parts, and ownership through the feeling of owning a body or body part. The narrative-self (or experiencing self) refers to the world through life stories; in this manner, agency may be defined as the sense that 'I am the one who tells the story' and ownership as the sense that 'I am the protagonist of the story'.

Following Gallagher's work, the terms agency and ownership have been used mostly in cognitive research examining the minimal-self; that is the bodily self or body consciousness [3–10]. In this domain, the sense of ownership has been defined as a 'pre-reflective experience or sense that I am the subject of the movement, that I am the one moving...' and the sense of agency as 'the pre-reflective experience or sense that I am the cause or author of the movement' [5,9]. Importantly, while body processing was extensively investigated for more than a century, agency and ownership have added another explanatory level by relating the more mechanistic body processing to a broader, self-referenced bodily consciousness [4,11]. In this Opinion article we attempt to also apply the concepts of agency and ownership to the narrative-self through the construct of cognitive mapping.

## Highlights

The concepts of agency and ownership were described two decades ago to explain the crucial relationship between the narrative- or experiencing- self and the experience. These concepts were applied mostly to bodily consciousness.

The construct of cognitive mapping allows these concepts to be applied to the relations between the narrative-self and the experience as represented on a cognitive map.

Computational models can be used to explain the integration of self-generated information (e.g., priors, beliefs, memories, simulations), the interplay between egocentric and allocentric reference frames, and personal schemata into the cognitive maps.

The concepts of agency and ownership may help us to understand psychological and clinical phenomena as well as their underlying neurocognitive and computational mechanisms.

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## Cognitive Mapping

More than 70 years ago, Kenneth Craik speculated that ‘the organism carries a “small-scale model” of external reality and of its possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future’ [12]. Tolman [13] further hypothesized that perceived stimuli are not connected by ‘simple one-to-one switches to the outgoing responses’, but rather are represented on ‘a tentative, cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and **environmental relationships**, which finally determines what responses, if any, the animal will finally release’ ([13], see p. 193). Decades later, mechanisms have been proposed to support mapping functions. O’Keefe and colleagues [14] studied freely moving rodents and revealed that specific hippocampal neurons fire whenever an animal arrives at a specific place in the environment (‘place cells’). Later, another type of cell was discovered in the entorhinal cortex, firing periodically at multiple locations to form a sixfold rotationally symmetric grid-like pattern across space (‘grid cells’) [15]. The activity of such types of cells provides the so-called ‘**cognitive map**’, a map-like representation of the environment that is used for active navigation and planning. In addition, several other cell types have been discovered [16]: head-direction cells encode the animal’s direction, which is crucial for self-location-based navigation; and border cells, encoding the borders within the environment (firing when one is close to a border) enable tuning of navigation according to the specific arena’s size. Even an artificial network armed with the simplest navigational tools (linear and angular velocity) developed units manifesting in a manner similar to grid, border, and head-direction cells [17,18]. Interestingly, cognitive-map-like organization and strategies are applied not only to spatial navigation but also to other modalities like time (encoding for specific time durations [19]), social space (relation to one’s social network), the localization of other animals in space, potential tasks and decisions to be made, predictions, or even ‘concepts’ of objects in the environment [16], suggesting a further implication of this system in the mental modeling of one’s surroundings. Such ‘**mental models**’ [20] may thus extend beyond the spatial environment (see [21,22]).

Of special importance for the narrative-self are temporal cognitive maps, representing the relationships between temporally noncontiguous events [19,23]. In the same manner that spatial cognitive maps represent navigation between nonadjacent locations by combining multiple pieces of spatial information, temporal cognitive maps enable ‘navigation’ between noncontiguous events by combining temporal information regarding different events [23]. This process is similar to the way in which events are spatially represented with respect to the narrative-self as well as to other events on a ‘mental timeline’ [24–26]. Likewise, cognitive maps may be regarded as a general system [27–29] representing relations between items in the world as well as the location of the narrative-self, in the immediate or imagined spatial environment, along the timeline of past experiences and future simulations, or on other planes such as social interactions with different individuals (unlike mere familiarity [30]).

## The Interplay between Egocentric and Allocentric Representations

An important property of the cognitive map is the interplay between bodily view (egocentric) and bird’s-eye view or allocentric representations (Box 1). In spatial cognition, navigation may be based on active movement of the body in the environment, while distances and angles of the body are computed as one explores the environment; this strategy is known as ‘path integration’ or egocentric navigation [31,32]. One’s self-location then serves as the basis for one’s behavior in the environment. By contrast, an allocentric strategy encodes information to form a landmark-based cognitive map. In this strategy, relationships among landmarks, as well as the subject’s stationary location, assist in defining one’s location within the environment. Importantly, these two strategies are in continual dialogue: allocentric representations of one’s self-location are

## Glossary

**Cognitive map:** a schematic-like mental representation of the relationships between entities in the world including places, events, people, or even concepts.

**‘Core’ network:** a network of brain regions, including the MTL, medial prefrontal cortex, posterior cingulate, and retrosplenial cortices and lateral parietal and temporal areas, that is engaged during both episodic simulation and memory.

**Ecologically valid:** psychological approaches or tests in which the settings, materials, and methods reflect the real-world environment. Ecological validity is especially important in personalized environments, as is the case in autobiographical memory or social cognition.

**Environmental relationships:** the way in which different entities in one’s mental environment (e.g., places in the spatial environment, events in the temporal one, people in the social one) refer to one another (and further on to the experiencing self). Relations may include cognitive distances (Euclidean or non-Euclidean), angles, phase scales, or frequencies, among others.

**Episodic simulation:** the mental construction of a specific hypothetical autobiographical event.

**Forward model:** uses an existing representation to simulate the next representation, based on error between internal, predicted outcomes and actual outcomes.

**Mental model:** a small-scale representation of the external world and the relationships between its various parts as well as the individual who represents them. A mental model enables an individual to use past experiences to predict future ones.

**Mental orientation:** the relations between the self and the internal representation she forms about the corresponding reference system (i.e., the external world), in space (places), time (events), and person (people).

**Schemata:** organized existing models that modify inputs perceived from the external world in relation to previous experiences, thus mediating between concepts one holds regarding the world and its actual perception.

**Self-agency:** in cognitive mapping, the sense that ‘I am the one who is generating an experience represented on a cognitive map’. The agency

updated by egocentrically derived changes of one's self-location and, vice versa, one's egocentric perception is changed according to the allocentric cognitive map, maintaining one's ongoing relations with the environment [11,33,34,84].

The egocentric-allocentric interplay of perspective-taking is not restricted to spatial cognition. In temporal cognition, for instance, visuospatial imagery of a coherent scene from a single viewpoint is crucial for the simulation of an episode [35,36]. Memories can be retrieved from an egocentric perspective, as most events are initially experienced, as well as from an allocentric perspective, as if one is seeing oneself participating in the memory from outside. Moreover, the particular egocentric perspective adopted during memory retrieval may also shape the constructive nature of memories [37,38]. The relation between egocentric and allocentric perspectives is associated with the cognitive distance [39] from a remembered event: recent autobiographical memories are more frequently associated with egocentric perspective, whereas remote memories are associated with allocentric perspective [40,41]. Shifting visual perspective during memory retrieval may reduce the emotional intensity of memories [42–45]. The natural egocentric perspective in long-term memory retrieval can be manipulated and updated when people imagine the possible (spatial) movements they can make within the remembered scene [46]. Moreover, it was shown that shifting of visual perspective during retrieval shapes remembering and memory constructions [46,47]. In social cognition the interplay between egocentric and allocentric (or alterocentric) frames of reference lays the ground for 'theory of mind' [48], in which mental states of others are modeled according to one's egocentric reflections as if she is in another's (alterocentric) shoes, an ability learned early in tales and stories [49], which may be crucial for social behavior.

### Agency and Ownership in Cognitive Mapping

We suggest that self-agency and self-ownership are critical components of cognitive mapping over the different domains (space, time, and person) and for the egocentric–allocentric translation embedded in this process. In the same manner that agency and ownership help in relating movements we initiate and sensations we perceive to our bodily (or minimal) self, we suggest that agency and ownership are crucial to relate our movement in the environment, which is continuously translated to a form of a cognitive map, to the narrative (or experiencing) self. Notably, agency and ownership are suggested not just as a metaphor or a conceptual framework but also as cognitive operators involved in the projection of information to and from the processing of the cognitive maps [1,9,18]. Gallagher's [1] original definitions will therefore be applied such that agency is defined as 'the sense that I am the one who is generating the experience represented on a cognitive map in my stream of consciousness', while ownership is 'the sense that I am the one who is undergoing an experience, represented on a cognitive map'. Following these definitions, agency is manifested here as a top-down process (self to map), which inserts self-generated 'priors' into the process of cognitive mapping, including expectations, simulations, and past memories regarding the environments and the self within it; ownership is a bottom-up process (map to self) in which one's existing model about the way she experiences the environment is updated through information gathered from the environment, including path integration and world information (Figure 2A; for a detailed model, see Figure 3).

Agency and ownership in cognitive mapping may be better understood through Gallagher's distinction between minimal-self and narrative-self. Minimal-self involves the immediate experience, unextended in time, and is therefore well expressed in bodily consciousness, since the embodied self is, by definition, here and now. The narrative-self, however, involves a continuum self that is more than a singular point, including an ongoing, gradually changing qualitative duration (the Bergsonian *durée* [50]) from past to future, and is also freely moving in space. Adapting a cognitive mapping model, rather than living in the here and now, the narrative-self 'lives' on a cognitive map that contains one's remembered past and one's imagined potential futures.

process may insert different priors or beliefs one has with respect to the represented environment.

**Self-ownership:** in cognitive mapping, the sense that 'I am the one who is undergoing an experience, represented on a cognitive map'. This implies an 'ownership model' that processes newly acquired world- and self-related information in an individual manner.

## Box 1. The Ego- and Allocentric Reference Frames

In their discussion of first-person perspective, Vogeley and Finke [11] distinguished between the reference frame (which may be ego- or allocentric) and the phenomenal level (which may be seen from first- or third-person perspective). Advances in both cognitive mapping research and navigation technology invite a new typology.

In an egocentric, body-centered representation (Figure 1A) one sees (unbroken lines) the world (blue) from her own point of view (red). It is from this subjective point of view that she also observes the interactions between other people or the relations between different locations, and imagines their relations to her own self (broken lines). The green line represents a barrier preventing the subject from seeing a third point and its relation to other locations/people/events. Such a representation is illustrated by Google Street View (lower row).

By contrast, in a pure allocentric, map-view representation (Figure 1B) one (red) imagines an object-to-object or world-centered representation, independent of her subjective point of view. In this representation, the observer position (gray) is marked within the environment but processed as other objects (blue) are. In this representation, all interrelations are imagined (broken lines). Such a representation is illustrated by a classical map (here from Google Maps, lower row).

In an 'omniscient' point of view (Figure 1C) such as an online navigation system like Google Maps, one knows not only what she may see from her own position but also what other people or locations see from their positions. This point of view may be regarded as a schematic ego- and allocentric hybrid.

Finally, the world may also be seen/imagined from an elevated, bird's-eye-view perspective (Figure 1D). In this representation, the individual sees the world, as well as her own self, from an elevated point of view. This position enables her to see the interrelations not only between oneself and the world but also between the different locations/people/events (object to object, including the one beyond the green barrier) and is therefore considered here as allocentric. This point of view has a special importance with respect to the difference between cognitive mapping in rodents and primates [100]. Such a view is embedded in the 3D feature of Google Maps (here in a satellite view).

Note that while the above is illustrated in the domains of spatial navigation, a similar notion applies to the representation of the temporal (events) and social (people) domains (Figure 1). Like locations, they may be mutually related or only unidirectionally or they may contain information known only to an omniscient agent (e.g., psychologist, confidant).

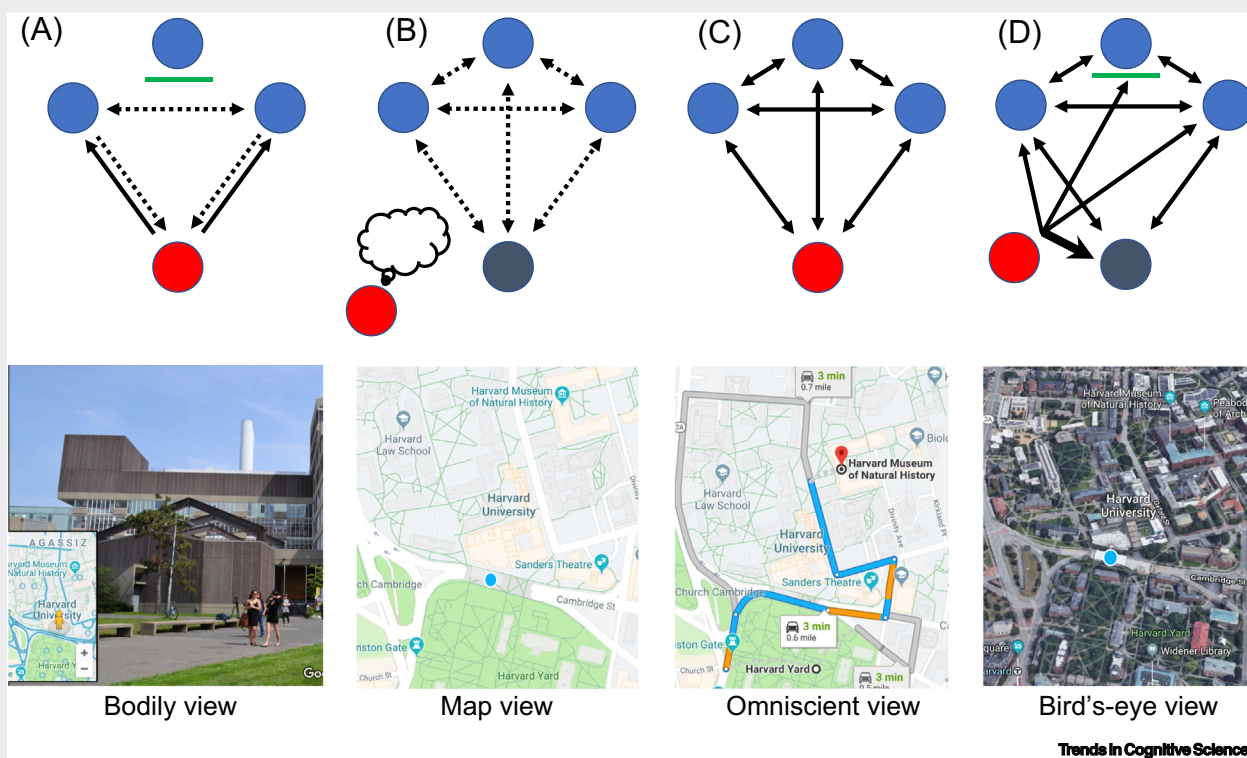
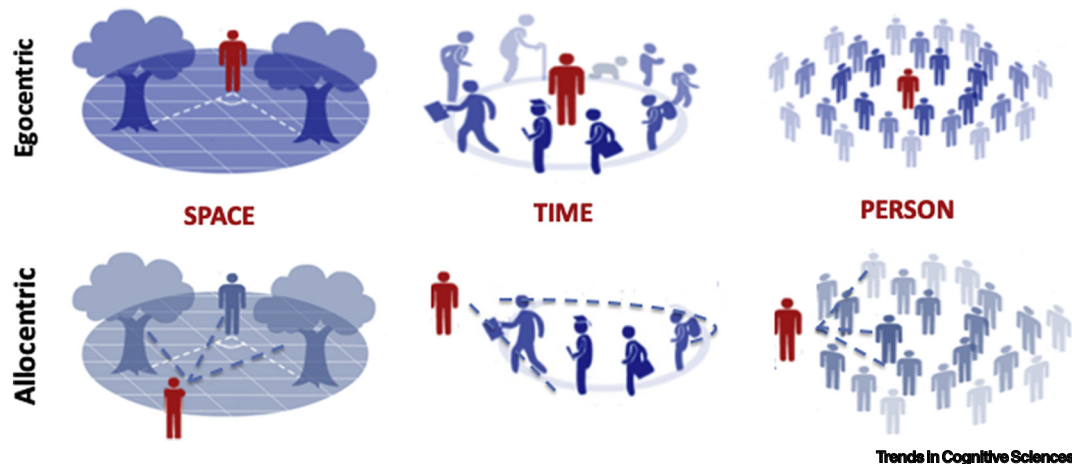


Figure 1. Illustrations and Realizations of Ego- and Allocentric Views.

Priors are inserted through agency into the newly generated map. World and egocentric feedback are influenced by an ownership model that the individual creates based on **schemata** used to process information [51–53] (Figure 3). Agency in the temporal cognitive





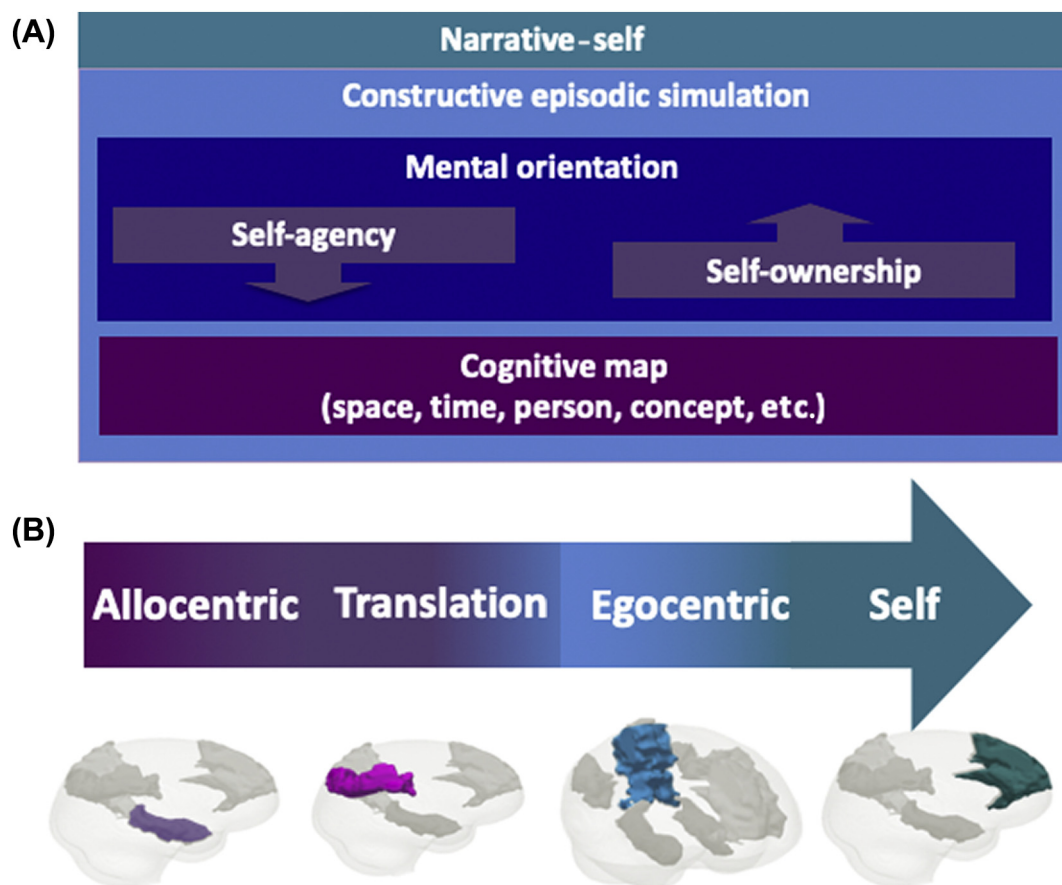
**Figure 1. Egocentric and Allocentric Perspectives in Space, Time, and Person.** Illustration of egocentric (upper row) and allocentric (lower row) representations of the spatial, temporal, and social world. Note that in both representations the narrative-self is embedded within the environment, but how the represented objects are related to one another differs (Box 1). Courtesy: Gregory Peters-Founshtein.

map [23] will be defined as ‘the sense that I am the one who is simulating this future or remembering this past scenario’ and therefore inserting memories and simulations to the experience. Ownership is ‘the sense that I am the one who underwent (or will undergo) this experience, combined by these events’. In space, the minimal-self is limited to the body and its peripersonal space (the immediate environment), whereas the narrative-self may reach more and more locations, beyond cities, countries, and continents. In the social domain, the narrative-self involves the experiencing subject as well as people around her [54]. Agency on the social cognitive map will be defined as ‘the sense that I am the one who generates and evaluate interactions with people around me (or social network)’. Ownership may be ‘the sense that I am the one who is involved in a social network’ [55].

To summarize, self-agency and self-ownership may be appreciated through their role in broader cognitive operations in which the narrative-self shapes the cognitive maps and interacts with them, including **episodic simulation** [35], **mental orientation** [56] (Figure 2A), or ‘self-reference’ [1,2,57,58]. The cognitive map depicts the relation between different ‘landmarks’ in the environment – places, events, or people – but how are these related to the narrative-self? We suggest that the agency process inserts into the map different beliefs, memories, and concepts acquired by the narrative-self across time and simulations of the map to be generated (Figure 3, upper branch). One’s own model of ownership is shaped and operates according to one’s experience, which influences the information inserted (Figure 3, lower branch). To reiterate, it is this information flow between map-based representation of the environment and the previously learned information and beliefs about the environment that enables one to process the changing environment with respect to the self and its cognitive state and to imagine possible future states to plan further behavior [35,59]. Agency and ownership are the cognitive operators that provide the bidirectional link between the constructed map and the narrative-self.

### Computational Neuroscience: Combining the Agency–Ownership and Egocentric–Allocentric Operations in Cognitive Mapping

The rich information available on the different cell types underlying cognitive mapping in the medial temporal lobe (MTL) and their various characteristics, as well as on relational processes, has led to the development of detailed computational models for potential mechanisms underlying

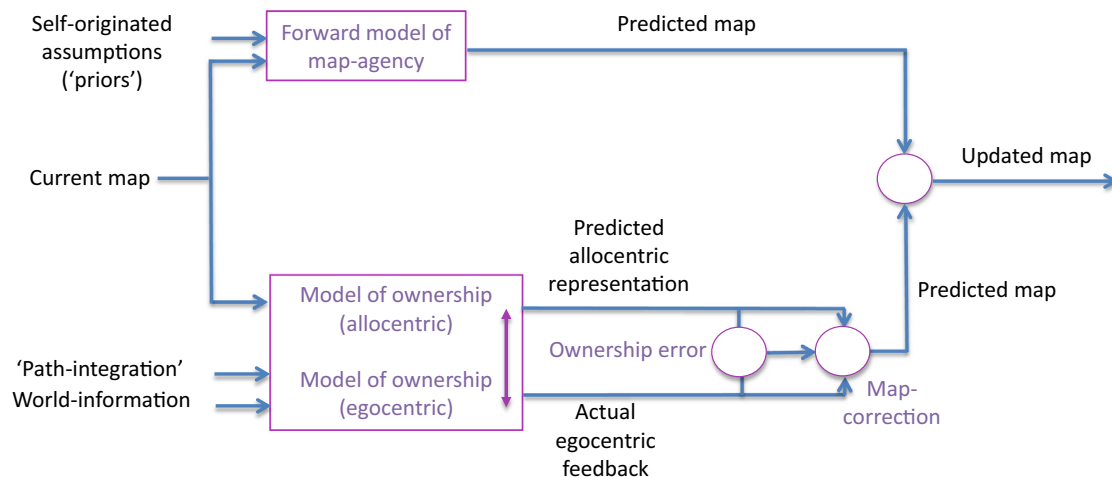


Trends In Cognitive Sciences

**Figure 2. From Cognitive Map to the Narrative-Self in the Core Network.** (A) Cognitive operations from cognitive map to the narrative-self. Self-agency and self-ownership mediate between the cognitive maps and the narrative-self. These operations are contained within mental orientation, which relates the internal representation of the self to the external world. Both are included in the operation of constructive episodic simulation. (B) From allocentric representation to the self in the core network. The flow from allocentric representation through agency and ownership to egocentric representation and the self is shown, in parallel to the corresponding regions in the 'core network' of brain activity for episodic simulation (medial temporal lobe, posterior cingulate/retrosplenial cortex, lateral parietal and temporal cortex, and medial prefrontal cortex, respectively).

cognitive mapping [17,18,33,46]. However, many questions about the relations between the narrative-self and cognitive maps remain open. How is the dialogue between the two managed? How are errors either in concepts adopted by the narrative-self about the world or in the map-like representation corrected from one version of the map to another? How are the egocentric–allocentric translations made? Are predictions and plans represented *a priori* on the maps? How are they updated over time? How does an updated map influence back the narrative-self? How does the updated map in one domain – for instance, space – influence a newly generated map of another domain (e.g., person)?

Models of agency and ownership may help in answering such questions. In view of the analogous relations between the agency–ownership loop and the sensorimotor one, such a model may rely on the fundamental principles of sensorimotor models [1,9], since these models are a prototype dealing with top-down self-generated movements and perceived bottom-up feedback. Agency, similar to motor control/command, is a top-down process (self to movement) and ownership, similar to sensory response, is a bottom-up process. In a seminal paper, Wolpert, Ghahramani and Jordan [60] sketched the principles of such models. Of specific interest are **forward**



Trends in Cognitive Sciences

**Figure 3. Agency–Ownership Interaction Model.** Modification of the model used by Wolpert *et al.* [60] is shown schematically, comprising two processes. The agency branch (upper) uses self-originated (top-down) agency-derived priors and beliefs and the current generated cognitive map to predict the next version of the map using a forward model. The ownership branch (bottom) uses one's personal model of ownership and egocentric–allocentric translation (the difference between the predicted allocentric map and the actual egocentric feedback perceived by path-integration and perceived-world information) to correct the predicted map. The next-generated map is dependent on these two processes (with different weighting). Circles represent operators along the model.

**models**, which are designed to predict the outcome of the interplay between top-down and bottom-up processes as well as to tune and optimize their mutual effect [61,62]. Building on this work (but see [63]), we suggest a forward model that includes a feedback loop between agency and ownership processes, applied on cognitive maps (Figure 3). In this model, an ownership branch (Figure 3, lower branch) converges the allocentric representation of one's self-location and world representation on the map as well as egocentric information (path integration and world information acquired during this process) through an ownership model. This model reflects the way in which each individual processes such information. An agency branch (Figure 3, upper branch) supplies self-originated assumptions (priors the self holds about the environments such as memories simulations or beliefs) to the information contained in the map. Notably, such a feedback model may capture the essence not only of the final maps but also of maps produced from each egocentric–allocentric translation. To reiterate, the proposed model is a combination of these agency and ownership processes and, together with the egocentric–allocentric translation, leads the subject to draw a new cognitive map. This process recurs again and again to optimize the map. The agency branch uses the current map and top-down self-originated information to modify the next version of the agency-based map by simulating the map using a forward model. The ownership branch uses a model of the subject's actual 'movement' in the represented environment (ownership model) to predict the allocentric representation, which is also updated by the actual egocentric feedback [64]. The ownership-model may be viewed as a schema [51,52] that characterizes the way in which the individual cognitive system perceives and processes world information and thus inherently influences the production and update of the map representation. The ownership error – that is, the difference between the allocentric generated map and the actual egocentric (path integration- and world information based) feedback [64] – is used to correct the newly generated map. The relative contributions of the two processes may be modulated for each person to optimize the map-construction process. Future studies may unravel whether changes in one's self-agency and self-ownership influence the generation, use, and interpretation of cognitive maps. For instance, the question of whether altering one's body agency or body ownership [65,66] would influence performance and strategies in navigation and orientation tasks could be investigated

experimentally. Simulations and data applied to the model may also be tested through modification of certain parts of the model and prediction of the resultant outcome.

### Neuroanatomy: Agency and Ownership in the Core Network

The mediation between the narrative-self and cognitive maps through agency and ownership may be further clarified in view of their underlying neuroanatomical basis (Figure 2B). The allocentric cognitive maps are based on MTL substructures that are also home to the involved cell populations [16]. The medial parietal region, including the retrosplenial cortex and the precuneus, is involved in the transformation, translation, and integration of egocentric and allocentric frameworks [32,33]. Notable in this vein is the posteromedial–anterior–temporal (PMAT) theory. This theory postulates the posteromedial system (including the retrosplenial cortex and parahippocampal region) to be involved in processing online context information in the domains of space, time, and person, referencing it to the perspective of one's self and storing that information in long-term memory (see evidence reviewed in [67]). On the lateral side, the temporoparietal junction (TPJ), mostly in the right hemisphere, was found to be crucial for a complete egocentric reference frame [11,68,69]. Finally, the medial prefrontal cortex and the anterior cingulate cortex are hypothesized to be involved in a self-referential mental activity of the narrative-self [53,54,70,71]. Experimental studies in the bodily consciousness domain have provided evidence relating the TPJ to agency processes and the medial prefrontal cortex to body ownership [8,68,72], associations that may be related to the self-originated character of agency and to the self-referential character of ownership, respectively. Together, these regions comprise the '**core network**' of brain regions that supports both the remembering of past experiences and the simulation of future experiences [35,59,73,74]. This network includes the MTL, medial prefrontal cortex, posterior cingulate, and retrosplenial cortices and lateral parietal and temporal areas [75]. Notably, the network overlaps substantially with the default mode network (DMN) supporting self-referential processes [70,76,77].

The division of labor between cortical and MTL substructures of the core network was demonstrated in several recent studies [78–81]. One study [78] used intracranial brain recordings in humans (epileptic patients) with electrodes located in both cortical and MTL regions. Patients were asked to imagine themselves (or 'travel' in time) in a specific time point that may be the present time or a potential past or future time. They were then asked to make judgements about different events with respect to the imagined time point. Results showed a clear temporal difference between the lateral-cortical and MTL electrodes: cortical electrodes were active early while 'traveling' in time and the MTL ones only later while specific events were referred to the narrative-self [78,82]. The application of agency and ownership may explain these distinctions: cognitive maps are based on cell populations in the MTL, while agency and ownership link these maps to the narrative-self, managed in cortical regions. The temporal distinction between the lateral temporal cortex and the MTL implies the involvement of agency processes in which the narrative-self (lateral cortex) may shape and affect cognitive mapping processes (MTL) in a top-down manner (self to map; Figure 2). For instance, while one is entering a certain environment, there are several priors one generates regarding the characters of this environment (e.g. size, height, colour) that may shape its representation as a cognitive map [83,84]. Accordingly, the suggested framework predicts that, while actively navigating a new environment and transforming egocentric and allocentric perspectives, a TPJ activation will be found, based on previous literature linking the TPJ with egocentric-to-allocentric transformation [11,69,70]. When an existing map is used and then transformed by the narrative-self (e.g., when expecting a certain environment but finally finding oneself in another type of environment), prefrontal or medial parietal regions will be active [53,67,83].



### Neuropsychiatry of Agency and Ownership in Cognitive Mapping

Agency and ownership in cognitive mapping may also carry important clinical significance. In his original paper, Gallagher [1] used the concepts of agency and ownership to explain schizophrenic symptoms of delusions of control and thought insertion. Patients with schizophrenia, he claims, may suffer a loss of the sense of agency for their own thoughts, which, in turn, enables the insertion of thoughts of reference by others into the minimal-self [85]. Several experimental works have shown distortion in these faculties in patients with schizophrenia [65,86,87].

The suggested agency–ownership model may help in the classification of several memory-related neuropsychiatric disorders [88] in the domains of space, time, and person. Most prominently, and as based on recent findings [89–92], we claim that Alzheimer's disease (AD) is a disorder in which the orientation of the narrative-self to the world is disturbed, encompassing agency and ownership processes. AD is clinically ill defined, and mere memory or cognitive complaints and tests are insufficient for the diagnosis and monitoring of disease progression [90,93]. It was further hypothesized that the egocentric–allocentric transformation, crucial for the creation of cognitive maps and thus spatial and episodic memories, plays a major role in the disease [90,94,95]. **Ecologically valid**, self-related approaches to test orientation and navigation helped to identify early disruption in young adults at genetic risk for AD and at an early stage on the Alzheimer's continuum [89,91]. Neuroimaging studies showed that brain regions affected by AD highly overlap with the core network, DMN and orientation system [89,90,96]. Based on this evidence, it is suggested that agency and ownership in cognitive mapping, and specifically translations from egocentric to allocentric reference frames and back, are impaired in the very early stages of AD and might therefore be of particular importance in detecting very early signs of the disease. Moreover, we propose that AD involves a failure of the agency–ownership interplay early in the course of the disease that declines monotonically as the disease progresses. This is compensated by cognitive mapping activity, which fails later with disease progression, leading to amnesic symptoms as known in AD. Experimental support for these hypotheses is needed [97].

Table 1. Memory-Related Disorders Classified According to Agency, Ownership, and Cognitive Mapping Disturbances<sup>a,b</sup>

Category	Domain	Disorder	Phenomenology	Anatomy
Agency	Space	Egocentric disorientation	Inability to represent the location of objects with respect to self	P
	Time	Age disorientation	Insistence on being younger than one's real age, even with correct knowledge of the current year and year of birth	Insula, P
	Person	Depersonalization	Feeling detached from one's mental processes or body, as if one is an outside observer	TPJ, P
Ownership	Space	Heading disorientation	Inability to represent direction of orientation with respect to the external environment	F, RSC
		Reduplicative paramnesia	Delusion that a place simultaneously exists in two or more locations or is transferred to a different location	F
	Time	Reduplicative paramnesia for time	Delusion that an event happens simultaneously in two or more locations or is transferred to a different time	F
	Person	Capgras/Fregoli	Familiar persons are believed to be imposters/belief that a stranger is a familiar person	F
Map	Space	Anterograde disorientation	Inability to create new representations of environmental information	MTL
	Time	Limbic encephalitis	Deficits in past remembering and future imagination	MTL
		Déjà vu	Feeling that events have already happened	MTL
		Timeline disorganization	Inability to obtain the correct sequence of life events	MTL
		Transient global amnesia	Loss of memory for recent events and an impaired ability to retain new information	MTL

<sup>a</sup>Abbreviations: P, parietal; F, frontal; RSC, retrosplenial cortex.

<sup>b</sup>For references see [88].

Other, less prominent disorders may be intimately related to agency, ownership, and cognitive maps separately (Table 1). Agency-related disorders involve conditions in which the relations of the narrative-self to the world are disturbed, as well as conditions in which the narrative-self falsely applies priors and beliefs to its surroundings. Such disorders mostly involve parietal lesions. In ownership-related disorders, there is a difficulty in correctly representing the self-relevant world and appropriate processing of world information, usually due to frontal lesions. In map-related disorders, the mapping process itself is disturbed, due to lesions in the MTL. The utility of this distinction may be appreciated through the case of topographic disorientation. Topographic disorientation, a disorder of spatial orientation and topographical memory, has been described by Meyer [98] and further detailed by several other prominent authors (see in [99]) at the beginning of the 20th century. One hundred years later, Aguirre and D'Eposito [99] further divided topographic disorientation into several disorders including egocentric disorientation, heading disorientation, and anterograde disorientation. The first involves patients who are 'unable to represent the location of objects with respect to self', which is an agency-related disorder; the second involves patients who are 'unable to represent direction of orientation with respect to external environment', considered here as an ownership disorder; the third involves patients who are 'unable to create new representations of environmental information', a map-based disturbance (for the temporal and social domains, see Table 1).

### Concluding Remarks

In conclusion, we suggest that agency and ownership of one's experience as represented on cognitive maps in the spatial, temporal, social, or other, more conceptual, domains are crucial in linking cognitive maps to the narrative-self and translating self-generated priors and egocentric perceptions to allocentric representations and back. It is this link that enables the relation of the more mechanistic map-like representation to the self who undergoes the ongoing experience in both a top-down (self to map) and a bottom-up (map to self) manner. This conceptualization invites further investigation of agency and ownership in cognitive mapping by means of theoretical hypotheses, psychological experiments, computational models, neuroimaging analyses, and neuropsychiatric explorations (see Outstanding Questions).

### Acknowledgments

The authors are grateful to Drs Morris Moscovitch, Mor Nitzan, Michael Peer, Greg Peters-Founshtein, Nimrod Shaham, Hugo Spiers, and Peggy St Jacques for helpful discussions and comments on parts of the manuscript. The authors' research contributing to this Opinion article is funded by the Israel Science Foundations (grant nos 2598/16 and 1306/18 to S.A.), The Orion Foundation, and the National Institute on Aging (grant R01 NIA008441) and National Institute of Mental Health (grant R01 MH060941) to D.L.S.

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### Outstanding Questions

How do changes in one's self-agency and self-ownership influence the generation, use, and interpretation of cognitive maps?

What are the relations between agency and ownership in cognitive mapping and other related processes such as bodily agency and ownership, sensori-motor processes, or action perception?

How well may the forward and feedback model of agency and ownership in cognitive mapping predict experimental findings?

How does the ownership model operate and how does it treat egocentric and allocentric processing?

How is this model expressed neuroanatomically?

How are disorders of agency and ownership in cognitive mapping represented in the different parts of the model?

How is the interplay between agency and ownership expressed in the clinical phenomenology, neuropsychological measures, and functional neuroanatomy of patients with AD?

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