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Towards a Taxonomy of Wayfinding Tasks: A Knowledge-Based Approach

Jan M. Wiener, Simon J. Büchner, & Christoph Hölscher
Center for Cognitive Science, University of Freiburg, Germany

Although the term "Wayfinding" has been defined by several authors, it subsumes a whole set of tasks that involve different cognitive processes, drawing on different cognitive components. Research on wayfinding has been conducted with different paradigms using a variety of wayfinding tasks. This makes it difficult to compare the results and implications of many studies. A systematic classification is needed in order to determine and investigate the cognitive processes and structural components of how humans solve wayfinding problems. Current classifications of wayfinding distinguish tasks on a rather coarse level or do not take the navigator's knowledge, a key factor in wayfinding, into account. We present an extended taxonomy of wayfinding that distinguishes tasks by external constraints as well as by the level of spatial knowledge that is available to the navigator. The taxonomy will help to decrease ambiguity of wayfinding tasks and it will facilitate understanding of the differentiated demands a navigator faces when solving wayfinding problems.

Keywords: taxonomy, wayfinding, navigation.

Introduction

Purposeful navigation between places is perhaps the most prominent real-world application of spatial cognition. Finding one's way is a ubiquitous requirement of daily life and it has received considerable attention in the research literature over the past 50 years. The term "wayfinding" has originally been introduced by

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Correspondence concerning this article should be addressed to Jan M. Wiener, Center for Cognitive Science, Freiburg University, Friedrichstr. 50, D-79098, Freiburg, Germany; email: mail@jan-wiener.net.

Kevin Lynch in 1960 and Golledge (1999, p.6) defines wayfinding as "the process of determining and following a path or route between and origin and destination". Humans solve manifold wayfinding tasks such as search, exploration, route following, or route planning in contexts including outdoor and urban environments, indoor spaces and virtual reality simulations. The cognitive resources required for these tasks differ considerably, both with respect to the format and content of spatial knowledge involved and with respect to strategies of problem solving, choice of perceptual cues from the environment and ultimately choice of movement sequences. The investigation of spatial representation format, cognitive processes and strategies for solving different tasks poses a key issue in spatial cognition research.

In order to systematically approach these issues, a taxonomy of wayfinding behavior, describing the different wayfinding tasks in detail, is of particular importance for a number of reasons: First, navigation research is characterized by a variety of paradigms and case studies. Without a taxonomy of navigation and wayfinding tasks, these studies are difficult to compare and to integrate. Two studies by Michael O'Neill (1991a, 1991b) illustrate this problem, as two rather different tasks are both simply labeled "wayfinding": While O'Neill (1991a) had participants search for an unknown room in a (familiar) university building, O'Neill (1991b) asked participants to identify the shortest route to specifically trained target locations. Second, navigation and wayfinding belong to the most complex cognitive operations. In order to successfully solve wayfinding tasks, navigators have to monitor external and internal cues, representations of space have to be formed and manipulated, etc. In order to uncover the dynamic and complex interplay of these different cognitive components, one must develop an understanding of how different wayfinding tasks relate to each other.

This paper aims to provide a taxonomy[1] of wayfinding tasks and their demands regarding spatial knowledge. The goal is to extend rather than replace existing classifications of wayfinding. While several authors have already identified different high-level wayfinding tasks, our contribution provides a more fine-grained (micro-level) differentiation based on the types of spatial knowledge that are involved. Knowledge about the location of a specific goal, as well as knowledge about a route or the environment as a whole crucially determine which wayfinding behaviors and strategies can be applied. Consequently, we suggest that a taxonomy of wayfinding must reflect these factors as well.

[1] Taxonomies provide a hierarchical structure of entities that allow the classification of instances of these entities. In the history of taxonomies in the sciences, the most prominent one may be the Systema Naturae by Carolus Linnaeus from the 18th century, defining the relationship among species.

A number of classifications of navigation behavior have been proposed in the literature (e.g., Allen, 1999, Mallot, 1999; Kuipers, 2000; Montello, 2001, 2005) of which we introduce the ones most relevant for this paper.

- Montello (2001, 2005) defines navigation as consisting of two components, locomotion and wayfinding. *Locomotion* refers to navigation behavior in response to current sensory-motor input of the immediate surrounding and includes tasks such as steering, obstacle avoidance, and the approach of a visible object in vista space. The term *wayfinding* subsumes a number of navigation tasks that share certain common features: they require decision making and/or planning processes, involve some representation of the environment and aim at reaching destinations beyond the current sensory horizon. Typical wayfinding tasks are, for example, search, exploration, and route planning.

- Mallot (1999) classifies navigation behavior according to their complexity and according to the kind of memory required to perform the behavior. A surprisingly rich repertoire of spatial behavior can be performed without spatial memory, such as course stabilization within a corridor, obstacle avoidance or visual approach. This class of navigation behavior is very similar if not identical to what has been referred to as *locomotion* (Montello, 2005). Integration of spatial information over time allows forming a working memory. Path integration – the integration of perceived ego-motion over time – is one example for a navigation behavior that can be explained by the integration of spatio-temporal information in working memory. Spatial information stored in long-term memory allows for various navigation abilities ranging from stereotyped behavior such as following a memorized route to cognitive – i.e., goal dependent and flexible – behavior, such as planning a novel route through a well-known environment.

- The most elaborate taxonomy of wayfinding comes from Allen (1999). He defines three wayfinding tasks: exploratory navigation, travel to familiar destination, and travel to novel destinations and provides prototypical examples. Relocating to a new city and exploring the surroundings is a typical example of exploratory navigation; commuting between home and work place is a typical example of travel to familiar destinations, and wayfinding guided by maps is a typical example of travel to novel destinations (cf. Allen, 1999). Allen furthermore describes six wayfinding means by which the tasks can be solved (oriented search, following a marked trail, piloting between landmarks, path integration, habitual locomotion, referring to cognitive map). Essentially, these means range from fundamental navigation mechanisms such as *following marked trail* or *path integration* to knowledge retrieval processes such as *referring to a cognitive map.*

For the investigation of the cognitive architecture underlying wayfinding – the question how different cognitive components and processes involved in navigation and wayfinding interact – the existing taxonomies have shortcomings. The most important one is that none of the taxonomies aims at a detailed analysis of different wayfinding tasks that would allow distinguishing, for example, between a search in a familiar and a novel environment. Montello (2001, 2005) does not distinguish between different wayfinding tasks and different kinds of cognitive components required. Mallot (1999) distinguishes between different memory systems and learning processes involved, but again does not explicitly differentiate between different tasks. Allen (1999) distinguishes between both, wayfinding tasks and wayfinding means. However, the wayfinding means remain underspecified. *Path integration* is an example for a rather well-defined mechanism (cf. Loomis, 1993). *Referring to cognitive map*, in contrast, is rather ill-defined possibly comprising a number of different operations that can elicit different kinds of knowledge. In addition, the distinction of three wayfinding tasks is fairly coarse. For example, “travel to a familiar destination” subsumes a number of different tasks, such as following a memorized path and planning a novel path to a known destination. These two tasks, however, are fundamentally different requiring different forms of memory and different information processing: For path following route-level knowledge is considered sufficient, while path planning builds about survey-level knowledge and involves spatial inference beyond simple recall from memory. In Allen’s taxonomy, four out of the six wayfinding means can be applied in all three wayfinding tasks. For the systematic evaluation of wayfinding behavior it is essential to classify wayfinding tasks and the cognitive processes that are involved on a more fine-grained level.

Towards a Novel Taxonomy of Wayfinding Tasks

A more fine-grained taxonomy of wayfinding should take task constraints and different kinds of knowledge into account and thus provide a more detailed (if not comprehensive) classification of wayfinding tasks. For example, consider search tasks: It is a basic property of a search task, that the location of the target (e.g. a specific object or room) is unknown. How does the search for a specific target differ in a familiar and in a novel environment? Search often takes place in unfamiliar environments, for example, when searching for a specific office in a large, complex university campus that one has never visited before. A search can also take place in familiar environments: Imagine, searching for a newly-opened bar in the downtown area of your hometown. What is the influence of spatial knowledge on the selection of a navigation strategy? In addition, which cognitive processes are shared by both tasks and which are specific for one or the other task?

We reason that a navigator's search behavior and search strategy will be heavily influenced by their degree of familiarity with the environment. In fact, it has been shown that familiarity with the environment does influence strategy choice in directed wayfinding tasks (Hölscher, Meilinger, Vrachliotis, Brösamle, & Knauff, 2006). The impact of the navigator's knowledge on cognitive task characteristics becomes even more apparent, when both extensive familiarity with the environment and information about the specific location of the target are available. Here the wayfinding agent can engage in a mental planning process to determine the shortest route to the target. These examples demonstrate that spatial knowledge is a key factor along which wayfinding tasks may be classified. Spatial knowledge has been distinguished between (at least) three levels of knowledge: knowledge about a point in space (e.g. a landmark, a destination), knowledge about a sequence of points (i.e. a path to a destination, often referred to as *route knowledge*), knowledge about an area, (i.e. knowledge about the spatial relation of at least two points, often referred to as *survey knowledge*; Siegel and White, 1975[2]: landmark, route, and survey knowledge; Golledge 1999: points, lines, areas).

In the following, we introduce a tentative taxonomy of wayfinding (see Figure 1) that extends earlier taxonomies. The starting point is the definition of navigation by Montello (2001), in which he describes navigation as consisting of two components: locomotion and wayfinding. We concentrate on wayfinding, i.e. navigation behavior that is directed to distant destinations or distant space, respectively. A crucial aspect of wayfinding is that paths to the destination(s) are not available from direct perception at the origin of travel. They have to be retrieved (or inferred) from long term memory, or if unavailable, strategies and heuristics have to be applied to traverse the unfamiliar parts of the environment.

Aided and Unaided Wayfinding

We further distinguish between wayfinding with and without external aids, i.e. *aided* and *unaided* wayfinding. As Allen (1999) pointed out, much everyday wayfinding behavior in man-made/urban environments is aided by some form of externalized representations, such as maps, signage, route instructions, or by modern hand-held computers and route planners. In some cases aided wayfinding is rather simple, for example, following a trail that is marked with signs to a distant terminal at an airport (c.f. trail following: Allen, 1999). Sign-following does not require considerable cognitive effort: After having detected the sign, the agent needs to identify the relevant information on the sign, match it with the target location and then execute the action that is declared on the sign (Raubal, 2001). In sign-following the path planning has already been done by the designer and as long as signs are put up reliably at every decision point the

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[2] Ishikawa & Montello (2006) have shown that learning of information on these three levels of knowledge need not follow a strict ascending order but can be obtained in parallel.

agent faces very little efforts of spatial reasoning. In the extreme case, sign following can be reduced to a locomotion task.

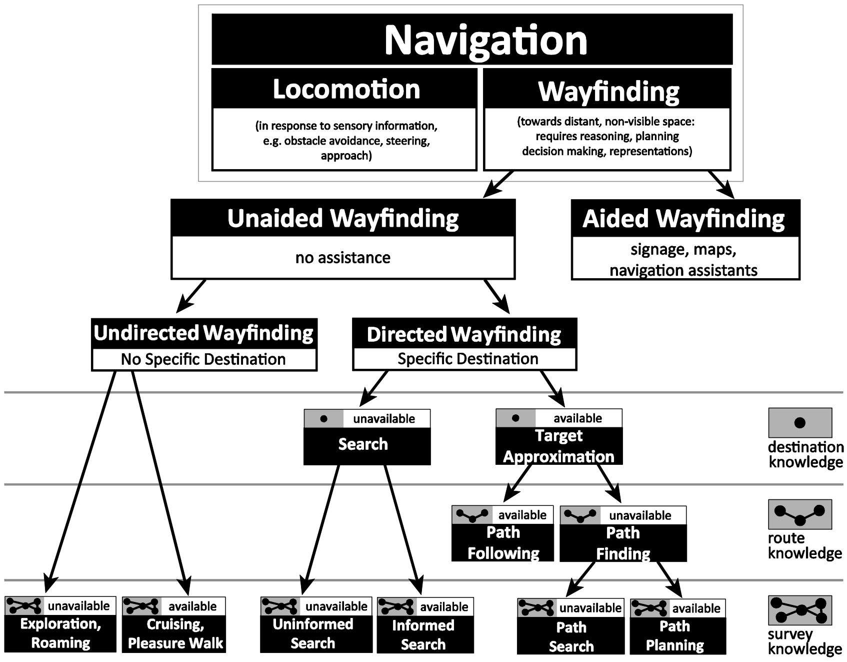

Figure 1: Proposed taxonomy of wayfinding tasks, classified by the existence of an external aid, a specific destination and the availability of different levels of knowledge.

In other cases, like wayfinding supported by a map, other cognitive processes play a crucial role, for example symbol identification, object rotation, self-localization, and establishing a match between the allo-centric view provided by the map and the ego-centric view that is experienced while moving through the environment (cf. Lobben, 2004). Taken together, decision making processes, memory processes, learning processes, and planning processes that are necessary to successfully solve unaided wayfinding tasks have been externalized in aided wayfinding. We reason that the cognitive demands of aided wayfinding are therefore fundamentally different from those of unaided wayfinding. In the following we will therefore focus on unaided wayfinding. Clearly distinguishing aided and unaided wayfinding is also helpful for comparing human and animal behavior, as animals are generally restricted to unaided wayfinding. This is especially relevant since animal models of spatial cognition on the behavioral as well as neural level have fruitfully inspired psychological research on human spatial cognition (e.g., Wang & Spelke, 2002).

Unaided wayfinding is first classified with respect to the agent's goal. The reason for travel through space can either have a specific spatial goal (e.g. reaching a particular location) or a non-spatial goal (e.g. pleasure when going for a walk along the beach). The difference between these two kinds of wayfinding is the existence of one – or multiple – specific destination(s). Navigation behavior without specific destinations is referred to as *undirected wayfinding.* Undirected wayfinding includes both exploring a new environment to learn about its structure, as well as recreational walks through familiar territory. Navigation behavior with specific destinations is referred to as *directed wayfinding.* Prototypical examples are the walk or drive from home to work or the search for a specific restaurant in part of town one rarely visits. Directed wayfinding has a well-defined stop criterion (i.e. reaching the destination) while the stop criterion in undirected wayfinding is determined by the navigator (e.g. having received enough joy from a walk) or by other, external constraints.

In a second step we classify directed and undirected wayfinding with respect to the navigator's spatial knowledge about three levels of geometric space: (a) knowledge about the target destination, (b) knowledge about the path towards the destination, and (c) knowledge about the environment. Here we refer to integrated knowledge about the environment, which is often called survey or cognitive-map like knowledge (e.g. Thorndyke & Hayes-Roth, 1982)[3]. Obviously knowledge (a) about and (b) the path to a destination applies only to *directed* wayfinding tasks, in which such a destination is specified.

Undirected Wayfinding

Let us first consider *undirected wayfinding,* i.e. navigation without a specific destination. The most important behavior in such situations is exploration. In exploration, the environment is unknown and the goal is to develop a representation of the environment. Exploratory behavior is often carried out after relocating to a novel city, or during holidays when exploring the neighborhood of the hotel (cf. Exploratory travel, Allen, 1999). Undirected wayfinding is also a frequent behavior in well-known environments. Imagine, for example, going window-shopping in your hometown. While you know the environment – the downtown area of your hometown – you are not planning a path to reach a specific destination, rather you are strolling along and direct your travel towards local sights of interest. Another example for undirected wayfinding behavior is taking a pleasure walk through a familiar forest. During such a pleasure walk, one is usually not striving for a specific destination (other than returning home at the end of his walk). Yet, navigation is not performed without intention, but might be aimed at receiving joy from walking through a pleasant landscape. At some point, of course, you will want to return to your home or car. Now you do have a specific destination and are no longer carrying

[3] For our purposes, the exact format of the cognitive map or survey knowledge remains underspecified and can be based on topological or metric relations.

out an undirected wayfinding task, but a directed one. We will come back to the question of how different wayfinding tasks can be nested or concatenated in the discussion section.

Directed Wayfinding

As defined above, *directed wayfinding* refers to navigation behavior in which a navigator is striving to approach a single or multiple destinations. The first distinction to be made is whether or not the navigator has knowledge about where the destination is located with respect to his/her current location or at least can infer this information through other familiar reference points (e.g. knowing that a specific shop is next to city hall). If that is not the case, the navigator is faced with what we refer to as a *search*. Search tasks can be further divided into *informed search* and *uninformed search.*

Search tasks

In *informed search* the navigator has survey knowledge about the environment – i.e. he/she has knowledge about the relation of different locations in the environment among each other. Imagine you are searching for a friend who is in one of the restaurants in the downtown area of your hometown. You certainly know the restaurants and how they are located in relation to each other, but you still have to search for your friend. In this case, you have knowledge about the environment, but you cannot tell where in that environment the actual target is located.

In *uninformed search*, by contrast, the environment is unknown. A typical example for an uninformed search is a firefighter, who has been told that there is still a person in the burning house. He or she is now searching for the person without any knowledge about the exact location of the person to be rescued.

The terms informed and uninformed search have also been used by Ruddle, Payne, & Jones, (1999), and they denote the same tasks that Darken & Sibert (1996) called *naïve search* and *primed search*. We prefer *informed* and *uninformed search* as these terms emphasize the information aspect of the knowledge rather than the state of the agent. It is well conceivable, that navigation behavior in informed and uninformed search and the navigation strategies applied will systematically differ. This is for a number of reasons: First, the navigator remains oriented in informed search and the risk of getting lost is minimized. The fact that the environment (i.e. the problem space) is known, allows the navigator to systematically search through the environment, to avoid redundant walking and thus optimize search performance. By contrast, in uninformed search a navigator cannot plan his/her search in advance, and if the search task is to be solved efficiently, attentional resources have to be attributed to monitoring, path integration, and other processes that assure that the same part of the environment is not searched multiple times and other parts of the environment are not ignored.

Target Approximation

If the navigator has knowledge about the destination, we refer to the corresponding behavior as *target approximation*. Target approximation can be further subdivided, depending on whether or not the navigator possesses path/route knowledge, i.e. knowledge about one particular path to the destination.

If the path is known, i.e., if it can be retrieved from long-term memory, the navigator faces a *path following* task. He has to match sensory information from the environment with the route knowledge he has memorized and he needs to execute and monitor the appropriate sequence of actions (e.g., Cohen & Schuepfer, 1980). A typical example is your everyday walk or drive to and back from work. This task requires little attentional resources, almost no reasoning and runs automatically; in fact it may get habituated (cf. Allen, 1999).

If no adequate route knowledge exists, i.e., no specific path sequence from the start point to the destination is memorized, the correct path to the destination has to be extracted or found (*path finding*). Here, a further distinction needs to be made between *path planning* and *path search*, depending on the navigator's survey knowledge about the environment.

In a well-known environment, in which the target location is known, but a direct path towards it is unknown, because this particular path has never been traveled before, navigators have to *plan* a path to reach the destination (*path planning*; Gärling & Gärling, 1988; O'Neill, 1991b; Wiener, Schnee, & Mallot, 2004). For this they have to refer to the survey knowledge they already have available, combine it in new ways and possibly make inferences about missing pieces. Compared to the other wayfinding tasks in our taxonomy, path planning is probably based on the most elaborate reasoning processes. The effort comes with a clear gain: Path planning can be employed to flexibly identify efficient movement sequences for new combinations of start and destination of a travel episode. McNamara & Shelton (2003) review findings in the neuroscience community indicating that clearly separable brain activation patterns also point to fundamental differences in the cognitive processes underlying path following vs. planning novel routes.

In unknown environments in which the navigator is informed about the location of the target, but is lacking information about the space between the current location and the target he/she has to search for a path (*path search*). This situation arises, for example, when a distant target location is visible in an otherwise unfamiliar surroundings. Imagine, you visit Paris and, of course, you are interested in visiting the Eiffel Tower. In some parts of Paris the Eiffel Tower is visible but you cannot approach it directly. You have to search for a path taking you to the bottom of the tower.

While path planning can rely on spatial inference to generate efficient paths to a destination, path search requires that the wayfinding agent employs heuristics to approach the destination in an iterative manner. This type of task has been used by Hochmair and Karlsson (2004) to investigate navigation strategies, namely the initial-segment and least-angle strategies. Both strategies rely on local heuristics of choosing long sightlines or immediate path options in the direction of the target location. But since no knowledge about subsequent movement options beyond the current vista space is available, navigators cannot plan ahead and are susceptible to detours and possibly the need for backtracking from dead-end paths. If visual access to the target is blocked during travel, one has to update the target location according to ego-motion information to guide the path search processes (see also Conroy Dalton, 2003).

Discussion and Open Questions

In this paper we have introduced a taxonomy of wayfinding tasks that extends earlier accounts (Mallot, 1999; Allen, 1999; Montello, 2001). We argue that knowledge about the location of a specific goal, knowledge about a specific path toward a goal, and knowledge of the environment as a whole crucially determine which wayfinding behaviors and strategies can be applied in order to solve a navigation task. Consequently, we build upon these three levels of spatial knowledge (cf. Siegel & White, 1975; Golledge, 1999) to provide a more fine-grained differentiation of wayfinding tasks. For the systematic investigation of the cognitive components and processes involved in different wayfinding tasks such a detailed specification of the task demands appears essential. We believe that the taxonomy presented here constitutes an important (initial) step towards the development of a more comprehensive understanding of the cognitive architecture of human (and possibly animal) navigation and wayfinding behavior.

This taxonomy is of tentative nature for a number of reasons:

First, while we have provided a more detailed differentiation of wayfinding tasks, a vital step is left to future research – the assignment of necessary and sufficient cognitive processes, components, and navigation mechanisms to solve the wayfinding tasks identified. I.e., answering the question, what information processing stages are required to solve a task A and what processes are required to solve a task B? For several of the wayfinding tasks in our taxonomy the real-world examples in the text already indicate principal differences, e.g. between search and path planning. We have identified the role of different levels of spatial knowledge. Further research and theoretical elaboration should be based on elaborate task analyses to identify and validate the underlying cognitive (sub-) processes in detail.

Second**,** the taxonomy is currently restricted to prototypical examples. For the sake of clarity we assume, for example, the clear-cut existence or non-existence of survey knowledge (cognitive maps). In everyday navigation, however, we rarely face situations in which we either have perfect knowledge about an environment or no knowledge at all. Hence, we are often engaged in navigation tasks in which part of the environment is known, while we have limited, fragmented or uncertain knowledge about other parts of the environment. One possibility to account for such situation is by assuming nested or concatenated wayfinding tasks. Consider the following situation: You are about to navigate towards a specific restaurant in a part of your hometown that you hardly ever visit. Such a wayfinding task can be divided into subtasks that can be expressed as wayfinding tasks defined in the current taxonomy. The first part of your navigation can be described as a *path planning* task, from your home towards the unfamiliar part of your hometown. As soon as you enter that area, you are missing detailed environmental knowledge and the task changes from *path planning* to *uninformed search*. We reason that combining the limited number of wayfinding tasks of our taxonomy in such ways will capture the majority of actual real-world navigation problems.

Third, the taxonomy currently ignores the existence of background knowledge. Even if a navigator is unfamiliar with a specific environment he can use schemata that he has learned during earlier experiences with similar situations. For example, railway stations, at least in European cities, are often located near the center of town; rest rooms in large public buildings are often located in proximity of staircases or elevators, etc. While until now very little research in spatial cognition has approached this important topic (but see Murakoshi & Kawai, 2000; Kalff & Strube, under review), it is obvious that such knowledge affects how we solve wayfinding tasks.

Fourth, this taxonomy of wayfinding tasks concentrates on the *usage*, rather than acquisition of spatial knowledge during wayfinding. The process of learning about an environment is not included in this tentative taxonomy. Background knowledge as well as survey knowledge about the environment that is to be navigated are generally acquired and memorized *before* the wayfinding task arises, often over many episodes or years. A navigator may also learn new information about the environment during a wayfinding episode. For example, if the navigator is performing a *search* task and returns to a previously visited location (after having moved in circles or backtracking from a dead-end), he may realize that he need not enter the same fruitless path option again, informing at least the local movement decision. Whether or not such experience or inference is stored beyond the current wayfinding episode is clearly beyond the scope of this paper.

Fifth, the taxonomy is currently limited to unaided wayfinding. We argue that cognitive processes and task characteristics in aided wayfinding may differ dramatically from the aided wayfinding tasks focused in our approach. It will clearly be valuable for basic research as well as for applications in Geography, Information Design or Human-Computer Interaction to develop such a fine-grained analysis of aided wayfinding tasks as well.

To summarize, the main contribution of this tentative taxonomy is the introduction of a systematic terminology to differentiate between wayfinding tasks that pose different cognitive demands on the navigator. We hope that the micro-level distinction of wayfinding tasks will help to further sharpen research questions about cognitive processes and strategies in wayfinding and to facilitate a better integration of knowledge gained across wayfinding studies that were difficult to compare in the past.

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