Spatial Biases in Navigation and Wayfinding

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Abstract

Navigating large environmental scale spaces typically requires navigators to select between a number of different routes available between the origin and destination. In this review we discuss strategies and heuristics that lead to systematic biases in route choice. Knowledge about the environment is our primary organizing principle for introducing literature that has explored biases on route choice. Specifically, we distinguish situations in which (1) navigators do not possess knowledge about the environment, in which (2) navigators have limited knowledge about the environment or the destination and situations in which (3) navigators are familiar with the environments or are using external representations such as maps.

Introduction

Imagine planning a route between two locations in your hometown. Even though you may have never navigated between the specific start and target location, you will be able to plan a route and navigate between these locations. Chances are that several alternative routes exist that are similar in terms of their length and the time needed to navigate them. So why did you decide for that particular route? While such choices (or solutions to the planning problem) may be random, the literature describes several situations in which participants exhibit systematic biases for one route over alternatives, even if alternatives are shorter or faster to navigate. In this chapter we provide examples for systematic biases in navigation and we discuss the psychological mechanisms that underlie these biases.

The example above describes a navigation behavior in a large scale environmental space (Montello, 2003). Such spaces are too large to be apprehended from a single vantage point and navigating environmental scale spaces typically requires movement between different ‘nested‘subspaces. Navigating nested subspaces poses a number of challenges that are not present when navigating vista scale spaces - i.e. spaces that can be apprehended from a single vantage point (Wolbers & Wiener, 2014) - and that may explain some of the spatial biases observed in navigation. For example, as navigators cannot oversee the entire environment without movement, they need to integrate information across space and time while moving through the environment in order to learn it. This integration can result in systematic distortions in spatial memory such as overestimation of distances between different parts of the environment (McNamara, 1986), which in turn can systematically affect navigation behavior.

Spatial biases in navigation and wayfinding, however, are not restricted to the generation of movement patterns, but may also manifest themselves in the selection of information that is encoded in spatial memory or the reference frames that is used for encoding information. For example, when navigating and learning large environmental scale spaces, navigators will typically memorize only a small subset of the abundant information they perceive: they will not memorize all environmental cues that may function as landmarks, but will concentrate on cues at navigationally relevant locations such as intersections (Aginsky et al., 1997). In order to explain biases in navigation and wayfinding behavior it is therefore important to consider which information navigators take into account.

Generally speaking, biases in navigation behavior, i.e. the systematic preference for particular paths, routes or specific movement patterns, result from the strategies that navigators apply. These strategies, in turn, depend on the knowledge that the navigator has about the environment and on the specific task that a navigator tries to solve (Wiener et al., 2009). In unfamiliar environments, for example, in which navigators lack detailed knowledge about the structure of the environment and the location of the goal, they have to resort to search behavior. Search strategies not only aim to find the target location as quickly and efficiently as possible, navigators are often also concerned with ensuring that they remain oriented and do not get lost. In familiar environments navigators may face a number of different tasks: They may search for a target whose current location is unknown. In this case, navigators will need to search through a familiar space, which means the risk of getting lost is minimal. Alternatively, and as in the scenario introduced above, they may know the environment and the location of the target, but have never navigated that particular route, in which case they are faced with the task of planning a novel route from their current location to the destination. Finally, human navigators often use external representations of space such as maps when planning routes. Maps provide navigators with the spatial information about unfamiliar environment required to plan routes. Spatial biases in route choices then depend on how information from maps is interpreted.

Given the importance of the navigator's knowledge about the environment for navigation behavior, we have structured our discussion of spatial biases in navigation and wayfinding as follows:

We will first consider navigation behavior in unfamiliar environments in which the location of targets is unknown. In such situations, navigation behavior in both animals and humans typically aims at exploring the environment or at foraging or finding specific items within the environment. We will highlight that search, foraging and exploratory behavior is not random, but guided by strategies which result in systematic biases or movements patterns. In doing so, we will discuss behavior at the level of the entire environment as well as on the level of single movement decision which are informed by the information that is available locally. Specifically, we will highlight how single movement decisions are informed and influenced by local cues that are available at the decision point.

We will then discuss systematic biases in route planning where environmental knowledge is available, i.e. in choosing between multiple alternative routes through an environment. In everyday life human navigators plan routes from memory (unaided route planning) as well as with the help of external maps (aided route planning). We will consider the psychological mechanisms and memory structures affecting aided and unaided route planning and we will argue that the interplay of working memory and long term memory plays a crucial role in explaining spatial biases in route choice.

A summary of the navigation strategies discussed in this chapter can be found in Table 1.

Search in open, unstructured environments

Most animal species spend a considerable proportion of their day foraging for food or searching to encounter other organisms. This foraging behavior is typically carried out without prior knowledge of the environment and often results in very specific movement patterns (see Figure 1). Similar trajectories have been reported in different animal species and they have particular regularities: there are times when the foragers intensify their search, changing movement directions frequently and therefore remaining in the same area of the environment. At other times they cover relatively large distances before intensifying search in another area of the environment. Such movement patterns have been described in many animal species and are thought to be optimal in situations in which targets are randomly distributed and scarce (Viswanathan et al., 1999, Viswanathan et al., 2001).

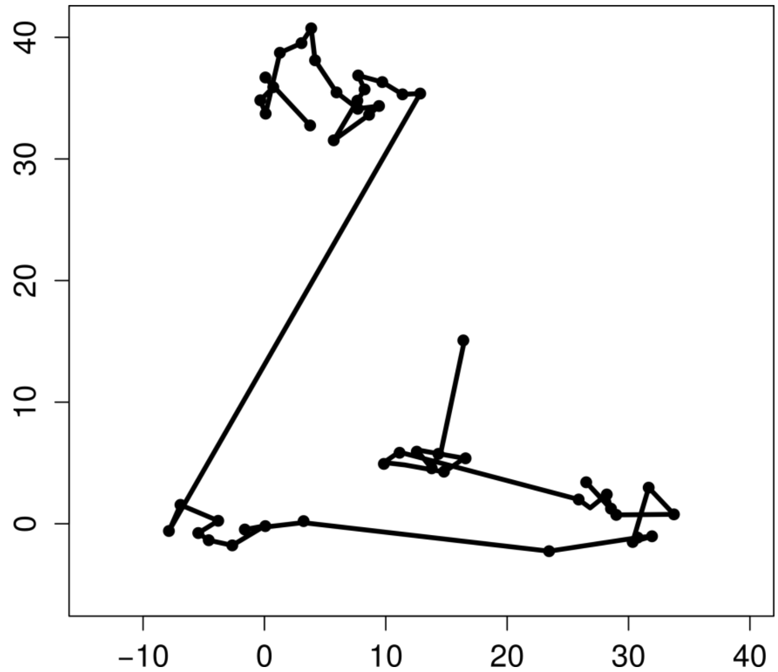

Figure 1: Example of a movement pattern generated by a Lévy process.

How can we explain such movement patterns? Foraging is often described as being based on a Lévy process (for an overview see: Viswanathan, 2011). A Lévy process is a stochastic motion in which successive movements are random and independent from each other. In other words, the lengths of single steps - here defined as straight line segments along the trajectory - are randomly sampled from a probability distribution. The shape of the foraging trajectory is defined by the exact nature of this probability distribution. Let us look at the trajectories in Figure 1 again: if divided into straight line segments, we find many short segments, few segments of medium length, and even fewer long segments. Analyses of trajectories from different animal species suggest that foraging movement patterns are power law distributed. Specifically, the frequency of step lengths closely fits the probability distribution function $P(l) \sim l^{-\mu}$ with $1 < \mu < 3$. Foraging trajectories that are generated by Lévy processes, so-called Lévy walks and Lévy flights, randomly sample the next step length from such a power law probability distribution.

What is the advantage of Lévy walks or Lévy flights over other types of random walk when foraging in an environment? As compared to other forms of random walk, such as Brownian walks, the few very long steps bring the forager to a different part of the environment and therefore reduce the risk that the same part of the environment is repeatedly searched.
The question whether human movements can be described by Lévy walks has been addressed using a variety of procedures. Brown and colleagues (Brown, Liebovitch, & Glendon, 2007) analyzed foraging patterns of Ju/’hoansi hunter-gatherer in the Kalahari Desert in Botswana and Namibia. Gonzalez and colleagues (Gonzalez, Hidalgo, & Barabasi, 2008) studied the trajectories of 1,000,000 mobile phone users. Rhee and colleagues (Rhee et al., 2008) analyzed 1,000 hrs of GPS traces of 44 individuals and Brockmann and colleagues (Brockmann,

Hufnagel, & Geisel, 2006) traced bank note circulation as a proxy for people's movement. Data from all these studies suggest that humans move in a manner similar to Lévy walks.

It is important to note that foraging behavior that is based on Lévy processes does not take into account when and where resources or targets are encountered. However, is it reasonable to assume that (human) foragers ignore such information? Imagine searching for mushrooms in a forest. As an experienced forager you know that many mushroom species tend to grow in patches. In other words, the distribution of mushrooms in spatially correlated; finding one mushroom therefore increases the chances of finding another mushroom of the same species nearby. In such situations it makes sense to respond to the encounter with a resource and to intensify the search in the area nearby.

Search behavior in which resource encounters result in increased turning frequency which slowly decreases without further encounters is referred to as *Area Restricted Search* (Tinbergen, Impekoven, & Franck, 1967, Hills et al., 2004). Similar to foraging behavior that is based on Lévy processes, area restricted search can lead to patterns in which agents seemingly switch between two different movement patterns: an intensive search with high frequency of turning and extensive search with low turning (e.g., Boyd, 1996, Hills et al., 2013). During the intensive search phase, a relatively small area covered in great detail; during the extensive search, agents cover a larger distance without sampling the environment in great detail.

Area restricted search is particularly beneficial in environments in which food resources are distributed in patches or clumps (Walsh, 1996). Increased turning rate and slowing down after a food encounter means that animals are intensifying their search around the area where food was last encountered. If no more food items are encountered - i.e. if the food patch is depleted - the turning rate decreases and animals move away and expand their search to new areas.

Strategy	Description
Search in open, unstructured environments with many goals	
Lévy walks	Randomly choose direction of next segment. Segment lengths are likely short and rarely long
Area restricted search	Increase turning frequency when finding much food (goals) and decrease when finding little food (goals)
Search in built environments	
Perimeter strategy	Move along the outer limits of an enclosed environment (e.g., building)
Central point	Stick to central locations in a building and explore from there
Information gain	Choose street which provides most future information
Route selection with limited environmental knowledge	
Edge following	If the goal is on an edge (street, river, coast) follow this edge
Central point	Stick to familiar (central) areas
Least angle	Always approach the target as directly as possible
Route selection with extensive knowledge - terrain and direction on map	
Flat trails	Prefer flat over hilly routes
South preference	Choose routes yielding initially or generally south (downwards) on a map
Route selection with extensive knowledge - reduce planning and memory costs	
Nearest neighbour	Move to the closest of multiple goals next
Longest initial segment	Among the routes leading towards the goal choose the one with the longest straight beginning
Focus on decision points	Only consider intersections where an alternative route might be selected
When in doubt follow your nose	Only consider turns and move straight by default
Defer path choice	Turn as late as possible
Least decision load	Choose the route with the fewest number of turns
Hierarchical planning	Plan a route the target region first and then the within the target region to the goal

Table 1: Overview of route choice strategies described in this chapter.

Search in built environments

The models describing foraging and search behavior that we discussed above typically do not consider environmental factors other than the distribution of resources or target. However, much human navigation takes place in built environments such as cities and complex indoor architectures and it is obvious that the form and structure of the built environment affect our navigation behavior: first, simply by restricting movements to the available path options; second, and more importantly in the context of this chapter, are systematic biases in search behavior that result from physical or architectural properties of the environment.

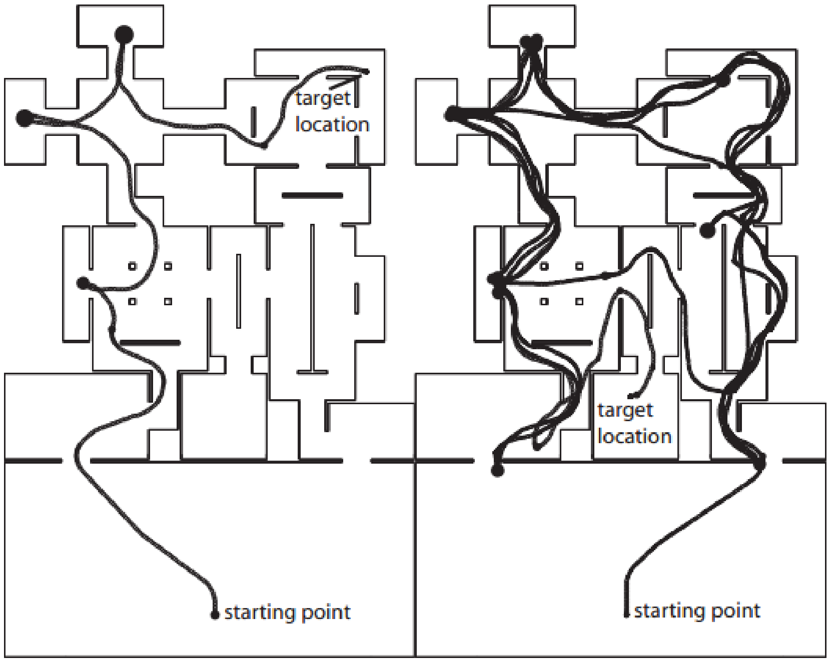

Figure 2: Two sample search trajectories. Left: with a target located along the perimeter; right: with a target located more centrally (from Büchner et al., 2009).

So far, only few case studies investigated search strategies in unfamiliar complex built spaces. Büchner et al. (2009), for example, studied the influence of target location on search behavior and search performance in large unfamiliar and complex architectural spaces. Figure 2 shows two example trajectories, highlighting a systematic bias in search behavior. Specifically, participants did not perform random searches, but tended to first explore the perimeter of unfamiliar environments and only eventually explore more central parts of the environment. This so-called perimeter strategy results in superior search performance when targets were located along the perimeter of the environment as compared to more central target locations, even if the central targets were closer to the start location of the search.

Another search strategy in unfamiliar complex architectural spaces that yields systematic biases in navigation behavior is the reference-point strategy (Hölscher et al., 2006). If asked to search for and navigate to several locations in an unfamiliar complex building, a strategy often used is to search and frequently return to the initial starting point (central point). In contrast to the perimeter strategy, such a central point strategy results in more star-like exploration or search patterns. The perimeter strategy and the central point strategy are likely to result from limited knowledge about the environment as both strategies reduce the risk of getting lost in unfamiliar environments.

The impact of spatial structure on search behavior

While the case studies introduced above reveal systematic biases in navigation behavior, they are difficult to compare and to integrate, as the behavior strongly depends on the specific architectural form and structure of the specific environment. To explore how the environmental affects navigation behavior more systematically and to compare navigation behavior between arbitrarily shaped environments, it is important to have objective and quantitative descriptions of environmental properties. Space Syntax (Hillier & Hanson, 1984) and isovist analysis (Benedikt, 1979) are techniques from architecture that allow the derivation of objective quantitative measures of global and local environmental properties. Both space syntax and isovist analysis have always been seen as closely related to human behavior.

Case studies have demonstrated that space syntax, which provides information about connectivity, centrality and control level of different parts of the environment, is closely related to pedestrian dispersion in the built environments (Hillier, 1996). Specifically, pedestrians display a systematic bias towards navigating along well integrated paths. Integration is a measure that describes how many turns a navigator has to make from one part of the environment (e.g. a street segment) in order to reach all other street segments in the environment.

While space syntax provides information about the structure of the entire environment, isovist analysis provides quantitative measures, such as the line of sight, about the visible space at specific locations within the environments. It is therefore better suited to explain behavior at single decision points which may lead to systematic biases in navigation behavior. A number of isovist measures have been shown to be associated with movement decisions (Emo, 2012, 2014, Wiener et al. 2012). When presented with images of decisions points and asked which of two path alternatives they would explore when searching through complex and unfamiliar built spaces, participants preferred to 'navigate' along paths that offered a longer line of sight and that had a higher local spatial complexity, i.e. that suggest that more decision points will be encountered along these path options. A possible explanation for these systematic biases is that these preferred path options promise to reveal more about the unknown space than the alternatives. In other word, by choosing path options with long lines of sight, searchers maximize the information gain when navigating and exploring unfamiliar environments.

Route selection with limited environmental knowledge

In case navigators have limited knowledge about the environment, the chance of getting lost during navigation is rather high. Getting lost can have a severe impact on the overall distance travelled and/or time taken to navigate to the destination - more so than differences in route lengths between alternatives (e.g., Meilinger et al., 2007). It therefore, makes sense to select or plan routes that minimize the risk of getting lost.

The minimal amount of spatial information that allows navigators to use route selection or planning strategies is information about the target location without information about the environment (uninformed search, see Wiener et al., 2009). For example, navigators may know that the destination is located along a river, coastline, or street but they are otherwise unfamiliar with the environment. In such situations navigators may use a strategy that is referred to as *edge following* (Allen, 1999; Hutchins, 1995). Essentially, they only need to decide on the direction in which they head off and then follow the edge until reaching the destination. While this may result in a route that is substantially longer than the shortest possible route, for example, if the river bends, it is a relatively safe route and the risk of getting lost is minimal.

Another simple navigation strategy that minimizes the risk of getting lost when navigators have limited information about the environment is to heavily rely on parts of the environment encountered before. For example, if some routes within an environment are known, this route network can be used to plan 'safe' routes, even if these routes require substantial detours. The central point strategy mentioned before is an example for such a strategy (Hölscher et al., 2006). Navigators tend to frequently return to already known parts of the environment in order to remain oriented rather than trying out different alternatives which might yield shorter routes. Here areas explored first – in buildings mainly the central points – become known and navigators stick to them.

In some cases, navigators may have knowledge about the direction and distance to the destination. Imagine, for example, navigating toward a tower that was visible from a distance, or pointed out by a pedestrian, without knowledge of the structure or street network of the environment. In this situation, navigators can use the *least angle* strategy (Hochmair & Frank, 2002). At each decision point, i.e. street intersection, navigators select the path option that is most aligned with the direction of the destination. Note, however, that without knowledge of the street network, this form of local optimization or hill-climbing strategy can lead to non-optimal paths, for example, when selecting a street which approaches the goal directly in the beginning, but then continues in a different direction or passes the goal requiring a detour.

Route selection with knowledge about the environment

When navigators possess good spatial knowledge about an environment, either in form of internal representations of space (cognitive maps) or by using externalized representations of space such as maps, they do not have to perform uninformed searches or focus on limited information, but can plan a complete route towards a target location. Systematic biases in route selection can result from different factors and may vary between navigators and environments depending on the exact planning criteria. For example, navigators may choose the route that is easiest to remember, routes that minimize the effort of navigation by choosing short routes or routes that go over terrain that is easy to traverse, they may prefer to walk straight most of the time or to approach their target as directly as possible.

Influence of terrain and direction on the map

A series of studies investigating route selection from maps have suggested that terrain elevation and route orientation on a map systematically affect route choices.

Terrain elevation can have a strong impact on the effort required to navigate along a route and has been shown to affect route planning. Traversing hilly trails will typically be more effortful than paths of similar length trails along a flat terrain. Indeed, when selecting between alternative routes from aerial photographs, participants tend to prefer *flat trails* (Brunyé et al., 2015).

When selecting routes from maps, participants show a bias for routes traveling initially or generally south over routes traveling north (Brunye, Mahoney, Gardony, & Taylor, 2010; Brunyé et al., 2012, 2015). This south preference bias was explained with a mental bias of estimating north locations as being of higher elevation as compared to south locations, in which case more southerly routes appear to be going downhill and therefore easier to traverse. Note however, that even though south routes are estimated as the "better routes" over north routes, navigators, when required to actually walk a route with help of a map show bias to select north routes and exhibit better navigation performance than on south routes (Wen & Kawabata, 2013). The most likely explanation for these preferences are alignment effects (Christoph Hölscher, Büchner, Meilinger, & Strube, 2009; Levine, Marchon, & Hanley, 1984). Specifically, north routes are leading upwards in the presented map and are therefore easier to translate to the egocentric perspective required for actual navigation. South routes, in contrast, have to be mentally rotated in order to align with the egocentric travel direction which affects performance. Interestingly, this example highlights a trade-off between the route presumably least effortful to walk and the route easiest to remember and use during navigation.

Reducing planning and memory costs

In route planning, navigators will typically aim for solutions, i.e. routes between their current location and the target(s), that are short, even though this is not necessarily the only criterion (see discussion above and below). Planning short routes through a network of streets or locations is considered an optimization problem. This is best demonstrated when assuming a typical street network which features an infinite number of paths between any two locations. Planning the shortest possible path in such a network requires precise knowledge of the environment either from memory or from external representations of the environment (such as maps). Planning the optimal path also requires the consideration and comparison of a large number of route alternatives, which is cognitively demanding. Navigators therefore use a number of planning heuristics and strategies to reduce the search space. While these planning heuristics do not always result in the optimal solution to the planning problem, they typically allow generating a reasonable solution quickly. In the following, we discuss planning heuristics and strategies that result in biases for particular solutions.

Heuristics for short routes

Rather than searching for the optimal global solution, navigators often use more local strategies or heuristics when planning short routes. One such local strategy that is particularly suited when planning and navigating multi-stop routes is the *nearest neighbor* strategy: Instead of planning complex routes in taking all destinations into account, human navigators often simplify the planning problem by simply approaching the nearest target locations repeatedly. Specifically, Gärling and Gärling (1988) demonstrated that pedestrian shoppers tend to first visit the most distant shop, most likely to minimize the effort of carrying bought goods, and then repeatedly select and navigate to the nearest target shop until all shops have been visited. It is important to note that this nearest neighbor heuristic does not guarantee to result in the optimal, i.e. shortest possible, solution, but will typically result in solutions that are not far off the optimum while reducing planning effort considerably.

Another approximation to the shortest route to a single target location is the longest *initial segment* strategy. When confronted with path alternatives presented on maps, participants preferred the paths with the longest initial straight segment in the direction of the goal (Bailenson, Shum, & Uttal, 1998, 2000; Brunyé et al., 2015). Although later route parts of the preferred paths may render two alternatives as equally long and complex, navigators seem to value the initial part of a path as more relevant for route choices.

The initial segment strategy and the least angle strategy (see discussion above) were also compared with each other (Hochmair & Karlsson, 2005). In a desktop virtual environment participants chose one of two alternative route segments both approaching a visible target in the distance more or less directly for a shorter or longer distance. Participants switched between least angle and longest initial segment strategies in a way that they minimized the overall distance to the target which also included moving from the end of the segment straight to the target. This suggests that navigators may balance both strategies and in support of the shortest overall route at least for simple routes with all relevant information visible.

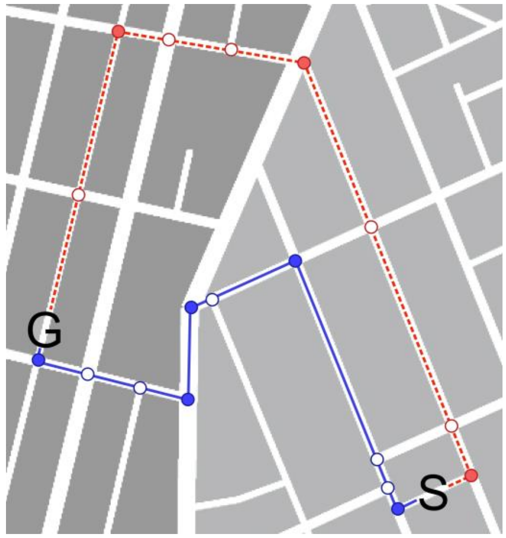

Figure 3: Schematic drawing of a navigation task and two alternative solutions: The navigators' task is to select a route from the start S to the goal G. Instead of planning and memorizing the whole route navigators can focus on the 10 decision points (circles) along on the solid blue route. When applying a when in doubt follow your nose strategy, navigators can reduce the required memory by concentrating on the 5 turns (filled circles). The least decision load strategy would suggest a different route (red dotted line) with even fewer turns, namely 3. Note, however, that this alternative is longer. These strategies can be combined with hierarchical planning, which states that navigators plan the route that allows for fastest access to the target region (dark grey houses). This would require 3 turns along the solid blue route and then an additional two turns to plan the rest of the route to the goal within the target region.

Reducing memory costs for/during navigation

When planning and navigating environments without the use of maps, information about the environment has to be retrieved from long term spatial memory and made available in working memory. Working memory is a capacity limited system (Anderson, 2000) and it may not be able to simultaneously keep all the spatial information required to plan the optimal route in working memory. This problem has been illustrated by Hölscher; Tenbrink and Wiener (2011) who asked participants to first plan and then navigate the shortest possible routes between several start and target places. Routes planned from memory were longer and simpler, mostly relying on main streets, than the routes that participants actually navigated shortly after reporting their route plan. When planning from memory, participants were not able to activate all the relevant information and were often forgetting smaller streets that would have resulted in more efficient routes. The way navigators deal with limited working memory capacity have been addressed in several studies as well as models of route planning which we will discuss below and which is illustrated in Figure 3..

One important way to reduce the memory costs associated with route planning is to focus on information that is essentially required for wayfinding and to discard all other information. As discussed above, navigation in built environments and even sometimes in the countryside is restricted to visible paths, streets, or corridors (Allen, 1999). This allows navigators to focus on decision points along their route and largely ignore information in between. Consistent with such a strategy, participants, when asked to describe environments or routes, mention objects (landmarks) located at decision points more frequently and recognized them more reliably than objects located elsewhere in the environment (Aginsky, Harris, Rensink, & Beusmans, 1997; Appleyard, 1969; Cohen & Schuepfer, 1980; Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Janzen, 2006). These results suggest that navigators primarily encode information at locations that require them to make decision, i.e. at navigationally relevant locations.

Encoding environmental information primarily around decision points will considerably reduce memory load. Memory load can be even further reduced by focusing on decision points with turns rather than considering all decision points. The '*When in doubt follow your nose'* strategy, i.e. to walk straight at decision points by default (Dalton, 2003; Meilinger, Frankenstein, & Bülthoff, 2014; Meilinger, Franz, & Bülthoff, 2012), is an example of focusing on decision points with turns. The *When in doubt follow your nose* strategy has been described when exploring novel virtual environments (Dalton, 2003), when memorizing and retracing novel routes (Meilinger et al., 2012), and when selecting and indicating routes within highly familiar environments (Meilinger et al., 2014). In these experiments, navigators recalled turns more often than straight intersections. Moreover, when asked to indicate how a route continued at single intersections, navigators performed better at intersections that required a straight continuation as compared to a turn. In other words, while navigators focus on turns when recalling environments and when planning routes, they have a bias to walk straight at intersections and have to override this default response when executing routes.

Another navigation strategy that can be interpreted as an implementation of the *When in doubt follow your nose* strategy is the *Defer path choice* strategy (Christenfeld, 1995). This strategy states that navigators have a tendency to turn at the last possible turning point. For example, if navigators walk towards a goal that is located in a parallel street they will move straight as long as possible before making the required turn in order to get to the street with the target. Such a bias to delay turns as long as possible was shown in route choices on maps, in vista, and in environmental spaces when route alternatives were identical in terms of their length and number of turns (Christenfeld, 1995).

In addition to concentration on turns, participants often also choose the alternative with the fewest number of turns (Golledge, 1995). Such a route can also be considered the simplest route. One possible explanation for this strategy, which has also been called *Least decision load* strategy (Wiener, Schnee, & Mallot, 2004), is that simple routes with few turns (i.e. route segments) minimize cognitive or memory load and reduce the chance of making errors during navigation.

Another way to reduce cognitive effort during route planning and navigation is to not plan and represent the entire routes in detail, but only the parts which are immediately relevant. Wiener & Mallot (2003) suggested a *Hierarchical planning* heuristic, that exploits the fact that people represent spatial information at different levels of detail (i.e. hierarchical spatial memory: Hirtle and Jonides, 1985). Specifically, they suggest that during planning navigators form a working memory representation of space in which the immediate surrounding is represented at great detail, while distant places are represented at higher levels of abstraction (regions). Planning a route to a location in a different region using such a *focal representation* will result in a detailed route plan for the immediate movement decisions only. The remainder of the route plan is represented at a higher level of abstraction. Route plans then need to be updated during navigation (see also Wiener et al., 2004). Similar strategies have also been suggested for building or building complexes in which navigators approach the target area (i.e., a building or a floor in a building) as directly as possible (Hölscher et al., 2006; 2009). Such hierarchical planning strategies reduce working memory load by only making available detailed information for the current surrounding. At the same time, planning costs are reduced, as the search space is reduced.

Influence of the structure of long term memory on route choices

Biases in route choice can result from planning strategies or heuristics. Biases in route choice can, however, also result from the structure of long term memory itself. We have already introduced the hierarchical planning strategy that depends on the hierarchical structure of spatial long term memory (Tversky, chapter x in this volume). It should be noted here, that different navigators, all relying on hierarchical route planning, may still come up with different routes - depending on how they cluster locations into regions. Specifically, dividing environments differently into multiple regions will also yield different route choices when planning the same route.

Another source for biases in route choices is *biases in long-term memory* itself. Such biases are common as laid out in detail in Chapter 16 of this book. For example, navigators recall edges such as rivers or streets as more straight (Byrne, 1979) and more aligned with the vertical or horizontal map orientations than they actually are (Tversky, 1981). Also intersections are often recalled having orthogonal street layout even there is a huge deviation from that in reality (Gillner & Mallot, 1998). When trying to directly approach a goal or planning the shortest route such memory biases will yield route choice biases.

Final considerations

In this chapter we highlighted the main sources for biases in human wayfinding and navigation. Our primary organizing principle for introducing biases on route choice was knowledge about the environment. Without knowledge about the environment navigators have to search for goals. They might do so systematically, for example, following the perimeter of a building or choose streets which promise larger information gain about an environment. Limited knowledge about the environment or the destination can be exploited when walking along edges or familiar areas or when directly approaching a goal location. Within familiar environments or when using external representations such as maps, navigators have all the required information to plan and choose between alternative routes. While most planning strategies aim to produce short routes or routes that minimize locomotion effort, we have discussed how other constraints such as limited working memory capacity or considerations such as minimizing the risk of getting lost affect route planning and can result in systematic biases.

While we have discussed a number of factors that may result in systematic navigation biases, the list is not comprehensive and we will briefly mention further factors that we cannot discuss in detail here: First, gender has been suggested to impact on environmental learning and therefore may result in systematic biases. Specifically, men typically report focusing more strongly on configurations as used in a least angle strategy, whereas women often report relying more on properties of the route (Lawton & Kallai, 2002; Lawton, 1994, 1996). Second, environmental properties have been suggested to influence navigation strategies. For example, in planning routes navigators aim to minimize the number of turns more in environments with a grid layout than in environments that consists of diagonal or curvilinear streets (Golledge, 1995). Third, even route direction of the same start-target pairs matters: participants may choose different routes on the way out and back (Golledge, 1995; Stern & Leiser, 1988). Fourth, route selection criteria also differ when planning a route between start and a single goal as compared to planning a route via a third location (Golledge, 1995) and change across the lifespan (Wiener et al., 2013). Finally, the way we acquire spatial knowledge may affects navigation: experiments suggest that configurational knowledge acquired through studying maps and route knowledge acquired through active navigation are memorized independently, even for highly familiar environments such as one’s home town (Meilinger, Frankenstein, & Bülthoff, 2013).

It should also be noted at this point that route choices and/or biases in everyday navigation can often be explained by various strategies or a combination of strategies. For example, choosing to walk along a particular long and straight street rather than choosing a more complex and windy path could be explained by the initial segment strategy, the defer path choice strategy and the least angle strategy. Moreover, route choices may also be informed by criteria that are not related to minimizing locomotion or planning effort. Navigators, for example, may choose the *most scenic route* or the *safest route* (e.g. Brunyé et al., 2015) even if that results in substantially longer routes. These considerations highlight some of the difficulties in addressing route choice criteria and strategies using experimental approaches.

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