# Chapter 8
# Effects of Landmark Position and Design in VGI-Based Maps on Visual Attention and Cognitive Processing

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**Abstract** Landmarks play a crucial role in map reading and in the formation of mental spatial models. Especially when following a route to get to a fixed destination, landmarks are crucial orientation aids. Which objects from the multitude of spatial objects in an environment are suitable as landmarks and, for example, can be automatically displayed in navigation systems has hardly been clarified. The analysis of Volunteered Geographic Information (VGI) offers the possibility of no longer having to separate methodologically between active and passive salience of landmarks in order to gain insights into the effect of landmarks on orientation ability or memory performance. Since the users (groups) involved are map producers and map users at the same time, an analysis of the user behavior of user-generated maps provides in-depth insights into cognitive processes and enables the direct derivation of basic methodological principles for map design. The landmarks determined on the basis of the VGI and entered as signs in maps can provide indications of the required choice, number, and position of landmarks that users need in order to orientate themselves in space with the help of maps. The results of several empirical studies show which landmark pictograms from OpenStreetMap (OSM) maps are cognitively processed quickly by users and which spatial position they must have in order to be able to increase memory performance, for example, during route learning.

**Keywords** Landmarks · Salience · Pictograms · Spatial memory

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D. Burghardt et al. (eds.), *Volunteered Geographic Information*,
https://doi.org/10.1007/978-3-031-35374-1_8

## 8.1 Introduction

The increasing relevance of mobility is linked to an increasing extent of using mobile navigation technology. Modern navigation and visualization technology depend on the processing of extensive spatial data, which must be provided and maintained in real time. A sub-project of the SPP 1894 “Volunteered Geographic Information (VGI): Interpretation, Visualization and Social Computing” of the Ruhr University Bochum and the International Psychoanalytical University Berlin investigates how wayfinding and navigation can be supported by user-generated geodata. The project addresses the growing interest in reliable spatial data, which extends far beyond the capacities of official geodata sets. The aim is to obtain quantitative data on the use of landmarks in maps in the formation of mental spatial models by means of empirical studies and to transfer these to cartographic applications. The focus of this research is thus on the representation, use, and interpretation of landmarks as they appear in map-based Web 2.0 services such as OpenStreetMap (OSM). The results are expected to further contribute to the development of automatic extraction processes in mobile map design (cf. Klippel and Winter 2005; Elias and Paelke 2008).

## 8.2 The Role of Landmarks in Self-Localization, Navigation, and the Formation of Mental Spatial Models

Effective navigation in space depends on continuous self-localization (Loomis et al. 1999). By using topographic objects in the environment as spatial reference points, self-localization can be achieved (Meilinger et al. 2006). In this context, landmarks, salient spatial objects (Sorrows and Hirtle 1999; Bestgen et al. 2017), play an important role in real-world and map-based navigation. From the perspective of their perceiver, landmarks pop out of their surrounding objects (Bestgen et al. 2017; Röser 2017). This increases their likelihood to be perceived and processed. Therefore, landmarks are more likely used as the spatial reference points required for self-localization (Sorrows and Hirtle 1999; Bestgen et al. 2017; Elias and Paelke 2008; Millonig and Schechtner 2007).

Due to their relevance in the context of self-localization, landmarks are also known to play an important role for orienting. Turn-off points of a route can be identified by recognizing landmarks located close to these turn-off points (Millonig and Schechtner 2007). Furthermore, landmarks along the route can help ascertain that one is still following a specific route correctly, even if these landmarks are not located close to a location where the travel direction needs to be adjusted (Anacta et al. 2017). The relevance of landmarks for navigation is also reflected in findings demonstrating that the availability of landmarks during navigation increases the accuracy of route finding (Ruddle et al. 1997) and user confidence (Ross et al. 2004).

When people perceive space, either directly in an environment or as a map representation, they gradually integrate the perceived spatial information into a mental spatial model (Millonig and Schechtner 2007). According to Siegel and White (1975), landmark-based spatial knowledge is the first building block for the development of a mental spatial model. By focusing on salient landmarks, people make sense of otherwise (too) complex environments. Thus, landmarks provide an abstraction layer that is easier to memorize than the unfiltered environment (Millonig and Schechtner 2007; Presson and Montello 1988). In this abstraction layer, spatial elements can be memorized based on their relative location of the reference points provided by landmarks (Golledge 1999; Richter and Winter 2014). In other words, landmarks form a framework with the help of which other topographic objects in space are remembered. However, memorizing only landmarks as spatial reference points does not result in a usable mental spatial model in the context of spatial navigation. People also need to identify and memorize route segments connecting the spatial reference points. Werner et al. (2000) describe such a network as consisting of "nodes" and "edges" (see Fig. 8.1).

If acquired within real-world space, spatial knowledge in the form of landmarks and routes is incipiently egocentric (Millonig and Schechtner 2007). However, with the integration of different viewing perspectives of space, an allocentric survey model is likely also being developed (Werner et al. 1997). The map-like structure of such an allocentric mental spatial model allows more complex and flexible spatial evaluations. Even landmark pairs, for example, that are not directly connected with a route segment can be set into spatial relation to each other within such an allocentric model. Additionally, each added route segment increases the number of potential routes (see Fig. 8.1). This allows, for example, estimating distances or planning alternative routes between specific landmark pairs.

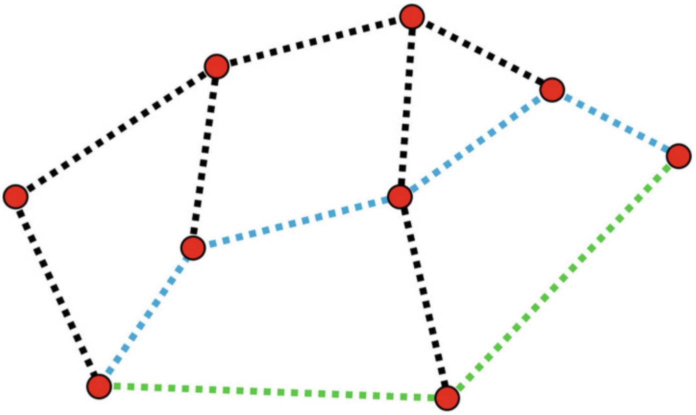

**Fig. 8.1** Landmark-based mental spatial model. Memorized landmark locations are represented by red dots (nodes). The dotted line connections (edges) between the landmarks each represent a memorized route between two nodes of the mental spatial model. The blue and green lines demonstrate that different routes between a start and target location can be selected if enough edges between node pairs have been memorized. Figure adapted from Keil (2021)

## 8.3 Identifying Landmarks

As demonstrated above, landmarks play an important role in spatial cognition, spatial behavior, and spatial memory. But how can we distinguish landmarks as relevant spatial reference points from less relevant topographic objects? So far, several attempts have been made to define landmarks from different perspectives. (Lynch 1960) focused on the inherent physical characteristics of urban objects and their visual contrast to features in the environment. Caduff and Timpf (2008) suggested a trilateral approach to identifying landmarks. The trilateral approach assumes that landmarks are created through an interaction between the observer, the spatial object, and its environment. According to Anacta et al. (2017), landmarks are objects with a fixed geographic location that are easy to perceive and recognize.

All of the aforementioned approaches to defining landmarks, either implicitly or explicitly, suggest a common characteristic of landmarks: they need to be salient. The salience of a topographic object describes and comprises characteristics that increase the likelihood of this object to attract the attention of (potential) observers in the environment (Itti 2005, 2007). Conversely, topographic objects that attract more attention than surrounding objects can be interpreted as being more salient (Caduff and Timpf 2008) and thus more likely to be used as a landmark (Röser 2017).

The trilateral approach of Caduff and Timpf (2008) already suggests that salience is not based on one single object characteristic that can be easily measured. Instead, to identify potential landmarks in the environment based on the salience of topographic objects, numerous characteristics need to be considered. To address this complexity of landmark salience, Sorrows and Hirtle (1999) take an approach that does not only refer to the appearance and position of a spatial element in an environment: They propose three categories of landmarks, visual (visual contrast), structural (prominent location), and cognitive (use, meaning) landmarks. Thus, it is proposed that the identification of landmarks also takes the semantics of the spatial object into account. To better distinguish the semantics from cognitive effects that could also affect the visual salience, the term semantic salience has also been established (Klippel and Winter 2005; Quesnot and Roche 2015). Due to the individual experiences and previous knowledge of a viewer, an exact determination of the meaning that a landmark (e.g., a building) has for an individual viewer can only hardly be defined and measured (Golledge 1991; Nuhn and Timpf 2017). One way out is to fall back on generally accepted classifications, e.g., road classifications (federal road, rural road, etc.) or monument classifications in the case of historic buildings, etc. (e.g. Raubal and Winter 2002). However, a study by Nuhn and Timpf (2019) indicates that personal attributions of meaning might be less important for the selection of landmarks than previously assumed. A landmark selection model containing personal information did not perform better than a model without this information. Although these findings do not solve the fundamental problem of the individual assignment of meanings to landmarks, they provide a perspective on the problem, at least in connection with visual and structural salience characteristics.

## 8.4 Landmark Representations in VGI-Based Maps

The main focus of previous research on landmark salience was directed at landmarks within real-world space (e.g., Anacta et al. 2017; Röser 2017; Sorrows and Hirtle 1999). However, psychological studies demonstrate that salience also affects visual attention in the perception of 2D information, e.g., on computer interfaces (Buscher et al. 2009) or in maps (Fine and Minnery 2009). This raises the question of how salience effects influence the perception and use of landmark representations in maps.

In most maps, real-world landmarks are represented by pictograms. However, the selection of landmarks to be represented in the maps occurs a priori. Thus, the selection of landmarks to be represented in maps is usually not based on direct interaction with the environment and user choices but rather based on established cartographic principles. As stated above, user characteristics (semantic salience) affect the selection of landmarks in real-world space. Additionally, visual salience characteristics (e.g., visibility from a specific viewpoint) can affect the selection of landmarks. In this context, an additional categorization of visual, semantic, and structural salience characteristics into active and passive salience can be used to illustrate the issue of landmark selection in maps. Passive salience depends on physical attributes of landmarks, such as size, color, or their function (Bestgen et al. 2017). It describes the potential of an object to attract attention based on bottom-up processes independent of individual characteristics of a potential perceiver (Caduff and Timpf 2008). The methods for identifying the passive salience of landmarks are explained in detail by Duckham et al. (2010), Klippel and Winter (2005), Nothegger et al. (2004), or Elias (2003). These approaches use, among other things, the results of statistical and data mining methods (Peters et al. 2010; Sadeghian and Kantardzic 2008). The concept of active salience, on the other hand, is based on the perceived, cognitive, and contextual appearance of a landmark, i.e., viewed from the perspective of the traveler (user), including his or her experiences, age, prior (cultural) knowledge, and the way he or she moves (Caduff and Timpf 2008; Millonig and Schechtner 2007; Zhu 2012). Taken together, exogenous (passive) salience patterns are contrasted with endogenous (active) ones. Both concepts influence the processing of map information and need to be taken into account for the identification and representation of landmarks. If the active user- and context-dependent salience characteristics are not considered, the set of landmarks selected to be represented in a map will not match the topographic objects selected as landmarks by the map users.

A special case in the context of landmark selection are maps based on Volunteered Geographic Information (VGI), such as OpenStreetMap (OSM). Producers of VGI map data (influenced by endogenous salience characteristics) simultaneously assume the role of the consumer (influenced by exogenous salience characteristics), i.e., two perspectives on landmark saliency are merged. There is no external decision-making authority, as is usually the case in map production. The resulting landmarks come from the actual spatial experiences of the volunteers (producers = consumers) themselves. Therefore, the study of map elements that are considered landmarks by such volunteers can provide valuable information on how landmarks are identified in maps in terms of their density and spatial arrangement and how user-generated landmark representations influence the formation and accuracy of cognitive representations (mental models) of the mapped space.

The VGI-based selection of spatial objects represented as landmarks in VGI-based maps is assumed to reflect the specific distribution of landmarks to each other (i.e., patterns) but also the relations to other map elements (non-landmarks) in maps that are required to solve spatial tasks. Since the mapping process of volunteers is affected by direct interaction with the mapped environments as well as their mental spatial representation of these environments, the landmarks represented in VGI-based maps are expected to reflect the patterns of landmarks required to represent space in a mental spatial model. This raises the question of how landmarks distributed in maps on the basis of empirically obtained rules (i.e., on the evaluation of landmark patterns created by volunteers) are used to create mental spatial models.

In real-world space, it is not only a single landmark in the landscape that is important for building survey knowledge of an environment. Rather, networks of several landmarks and the relations (e.g., distances or routes) between them must be considered (Herman et al. 1979; Werner et al. 2000). In a map, an interaction or pattern of several landmarks could therefore support the function of structuring (map) spaces and thus possesses a function for the construction of more accurate mental models in the same way (cf. Golledge 1993). Again, if the active user- and context-dependent salience characteristics are not considered, the set of landmarks selected to be represented in a map will not match the topographic objects selected as landmarks by the map users. In addition, it can be shown that landmarks are used in spatial learning to relate spatial objects to them (Ferguson and Hegarty 1994; Golledge 1999). Thus, visual attention directed toward specific landmarks due to their salience may not only affect spatial memory of the landmarks themselves. The availability of salient landmarks may also affect spatial memory of surrounding spatial objects or routes.

However, it needs to be considered that the salience and perception of landmarks in real-world space differs from the perception of landmark representations in maps. In real-world space, landmarks are only potentially salient if they are within the line of sight of the observer. This excludes many proximate landmarks that are not visible, for example, because they are hidden behind other spatial objects (cf. Lynch 1960). In maps on the other hand, each represented landmark is potentially visible. In this case, which landmark representations are perceived depends on the salience characteristics and/or task requirements. Therefore, how salience or spatial tasks affect the use of landmarks in maps (opposed to real-world landmarks) could affect performance in spatial tasks such as self-localization, orientation, and navigation, as well as the formation of mental spatial models based on map perception.

Not all graphic elements of a map share the same relevance for the formation of cognitive map representations as the selected (higher-level) landmark structures. The analysis of task-dependent salience of VGI-based map elements (here OSM maps) is therefore expected to support the identification of a working definition of the required spatial reference points (specifically landmark representations) that need to be visualized to ensure effective spatial information transfer. This might lead to new content structures that make it easier for map users to associate objects to be learned in a map with a higher-level frame of reference. The results of several studies contained in our project on the semantic, visual, and structural salience of VGI-based landmarks provide insights into the selection of spatial reference points in maps during the acquisition of spatial memory. Thus, these findings contribute to the development of guidelines for task-oriented map design that support the formation of mental spatial models.

### *8.4.1 Semantic Salience*

Semantic salience refers to semantic properties that affect the likelihood of an object to draw attention. As demonstrated by Pilarczyk and Kuniecki (2014), semantically salient stimuli attract visual attention, and the semantic features of a stimulus can in some cases even have a stronger effect on the direction of visual attention than the visual features. Different characteristics that affect the semantic salience of topographic objects have been suggested over the years. Some suggestions focus primarily on generalizable characteristics like cultural and historical significance or the purpose or function of an object (Claramunt and Winter 2007; Nothegger et al. 2004; Raubal and Winter 2002; Röser et al. 2011). These characteristics suggest that semantic salience is an intrinsic bottom-up property of an object that is not affected by the observer. Based on these suggestions, a church or a police station should be semantically more salient than a common residential building. Other approaches to assess semantic salience argue that top-down processes based on knowledge and preferences of an observer affect the semantic salience of topographic objects (e.g. Golledge 1991; Nuhn and Timpf 2017; Quesnot and Roche 2015). For example, a residential building can—in some cases—even be semantically more salient than a church or a police station if the observer lives in it.

In the context of map elements like landmark representations, assessing semantic salience faces issues, which are unique to the medium. First, landmarks are usually represented in maps as pictograms. In most cases, these pictograms do not reflect the visual characteristics of the represented landmarks but are designed to reflect the purpose or function of the landmark. This abstract representation of landmarks can override the semantic associations with a landmark. For example, your favorite restaurant located in a beautiful old building could be represented by the same pictogram as each other restaurant. On the other hand, a map pictogram can also communicate semantic information that is not effectively communicated by the visual appearance of the real-world object represented by the pictogram. It is also important to consider how the pictogram design affects to what extent map users are able to interpret the purpose or function of the represented landmark. For example, some pictograms might only be used in specific cultures or might have different meanings in different cultures (Spinillo 2012). Thus, pictogram designs need to be selected based on the intended user group of a map.

In a first study of our project, we investigated to what extent people understand the meaning of landmark pictograms (meaningfulness) and how the ability of a pictogram to communicate its semantics affects the attraction of visual attention (semantic salience) and the ability to memorize the pictogram (see Keil et al. 2019). We chose to investigate a set of 153 pictograms obtained from OSM. The map content and design of OSM are provided and influenced by a large worldwide community of volunteers. This is assumed to be reflected in the pictogram design and the accessibility of pictogram semantics within different cultural groups.

In a recognition design, sets of 12 pictograms (see example in Fig. 8.2) were shown to the participants. After a distractor task, participants had to identify the previously shown pictograms within a set of 24 successively shown pictograms. During the encoding phase, fixations on the pictograms were recorded with an eye tracker. In the second half of the experiment, participants successively saw the 153

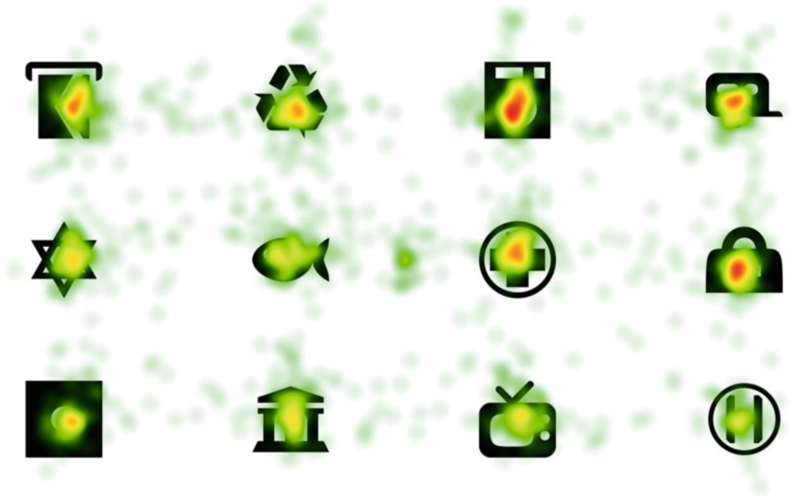

**Fig. 8.2** Fixation heat map. In the study, participants saw and had to memorize sets of 12 landmark pictograms. Semantic salience of the pictograms was assessed based on the visual attention directed toward each pictogram, as reflected in the measured fixations. In the example above, the helipad pictogram (down right) was fixated less often than the postbox pictogram (top left) and was therefore scored as less semantically salient. Potential order effects in the stimuli (e.g., based on reading direction) were addressed by varying pictogram locations between trials

pictograms. Each pictogram was shown together with a continuous scale that was used to assess to what extent participants were certain to understand the meaning of the pictogram (meaningfulness).

The findings demonstrate that pictograms with a very low meaningfulness rating attracted more visual attention and were recognized more often. An explanation of this unexpected finding needs to consider the experimental design and the general source of salience, which is a contrast with surrounding stimuli (Claramunt and Winter 2007; Sorrows and Hirtle 1999). Most of the 153 pictograms were rated as having a relatively high meaningfulness. Therefore, the few pictograms with a low meaningfulness were the ones with the highest semantic contrast. Consequently, as the semantic contrast is assumed to direct visual attention, the few pictograms with a low meaningfulness should also be the ones with the highest semantic salience. As selective visual attention has been associated with improved object learning (Walther et al. 2005), this also explains the better memory performance of landmark pictograms with a low meaningfulness.

However, it is important to also consider that the perception of landmark pictograms in this experiment does not match the perception of landmark pictograms in their “natural” environment. In OSM and other maps, semantic pictograms are surrounded by unified representations with a low meaningfulness, for example, buildings, roads, or green spaces. Thus, pictograms with a high meaningfulness should have a higher semantic contrast within a map and therefore a higher semantic salience. Furthermore, due to the higher selective attention, landmark representations in maps with a higher meaningfulness are assumed to be more likely to be stored in a mental spatial model (Walther et al. 2005). Taken together, the study provides an approach for assessing the semantic salience of landmark pictograms and demonstrates that semantic salience affects the attraction of visual attention and the memory of map elements.

### *8.4.2 Visual Salience*

Visual salience is probably the most investigated salience characteristic. It describes the visual contrast of an object to its surrounding objects and depends on parameters as illumination, size, color, texture, or shape (Clarke et al. 2013; Davoudian 2011; Duckham et al. 2010; Röser et al. 2011) and has been demonstrated to direct visual attention to stimuli (Wenczel et al. 2017). Commonly used examples of visually salient landmarks used for orientation and navigation are large or tall buildings, unique objects like statues, or buildings with an eccentric architecture or uncommon visual features (Klippel and Winter 2005). According to von Stülpnagel and Frankenstein (2015), visual salience affects the selection of spatial objects as landmarks for orientation. In other words, people look for visually salient objects that can be used as the spatial reference points required for making sense out of space and building mental spatial models (cf. Clarke et al. 2013).

Opposed to semantic and structural salience, the allocation of attention based on visual salience has been argued to be a stimulus-driven bottom-up process (Itti 2005; Ouerhani et al. 2004). This is supported by neurological findings demonstrating that the ability to perceive feature contrasts as the foundation for visual salience is located in the V1 area of the visual cortex (Li 2002). This means that the visual salience of visual stimuli is evaluated in an early and automatic stage likely before top-down processes affect the direction of visual attention. Its dependence on feature contrast means that visual salience is a context-dependent characteristic. An object is visually salient relative to its surrounding objects (Claramunt and Winter 2007; Klippel and Winter 2005). Thus, a tall building might not be visually salient if it is part of the skyline in a large city. On the contrary, a small building can be visually salient because it is surrounded by tall buildings.

Visual salience has been intensively investigated both for real-world objects like buildings or facades (e.g., Davoudian 2011; Franke 2021; Dong et al. 2020; Röser 2017; von Stülpnagel and Frankenstein 2015; Wenczel et al. 2017), but also for the perception of 2D stimuli, for example, computer interfaces or images (e.g., Clarke et al. 2013; Ouerhani et al. 2004; Sutherland et al. 2017). However, the effects of visual salience on the perception and processing of maps and landmark representations have received little attention in the literature so far.

The design of map elements is often not based on the visual features of the represented real-world objects. Streets, buildings, green spaces, and water bodies are represented by geometric shapes, and the colors of these shapes are determined by the map design guidelines (Dickmann 2018). Landmarks, on the other hand, as mentioned earlier, are usually represented as specific semantic pictograms based on the semantic categories they are assigned to (e.g., restaurants, shops, statues, etc.). In both cases, the individual visual characteristics are lost due to the type of representation. Thus, the visual salience of a real-world object does not match the visual salience of its map representation. Furthermore, opposed to real-world environments, it is easily possible to adjust the visual characteristics of object representations in a map and, consequently, the visual salience of specific map elements.

In a second study of our project, we explored how adjustments of map design can be used to systematically direct visual attention toward specific map areas. Furthermore, we investigated to what extent different map designs and the resulting visual salience differences of specific map regions affect spatial memory. The full study is described in detail in Keil et al. (2018). As study materials, we obtained maps from OSM and added routes to the maps. As a second stimulus condition, map areas offside the route (more than 10 pixels from the route) were displayed transparently (see Fig. 8.3). This was meant to reduce the visual salience of the areas offside the route and expected to direct visual attention toward the map areas close to the route. Participants saw the maps for 30 s and were asked to memorize the route (encoding phase). During this phase, fixations on the map areas were recorded with an eye tracker. Two different map areas of interest (AOIs) were defined. The first AOI contained the route and the area 10 pixels around the route, thus the area which was not transparent in the second stimulus condition (route AOI). The second

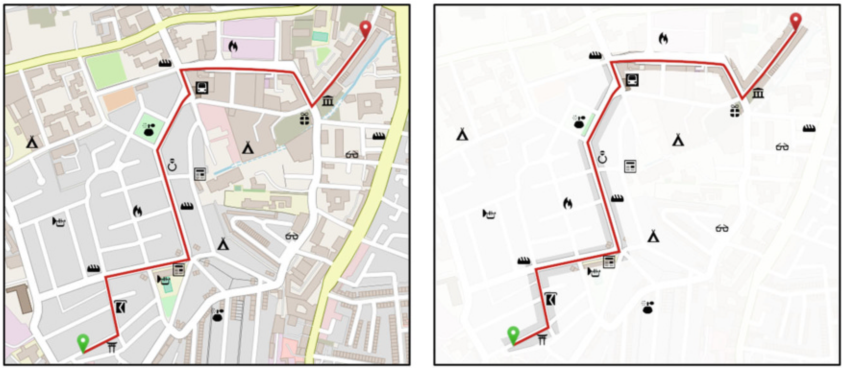

**Fig. 8.3** Stimulus conditions. Maps were obtained from OSM (© OpenStreetMap contributors), and a route was added. For the second stimulus condition, areas offside the route (more than 10 pixels) were displayed transparently. Eye tracking was used to record fixations on the area close to the route and the area offside the route

AOI contained the rest of the map (offside route AOI). Each fixation was recorded according to the AOI it targeted at. After the encoding phase, participants were shown four versions of the previously presented map, either containing the correct route or a slightly manipulated route. For each map, they had to decide whether the displayed route matched the previously learned route.

The results show that significantly fewer fixations were directed at the map areas offside the route (offside route AOI) when these areas were transparent. Fixations on the area around the route (route AOI) did not differ significantly between the standard map and the transparent map. Thus, we were able to demonstrate that changing map design, and consequently, the visual salience of specific map elements affects the distribution of visual attention across the map. Interestingly, the fact that landmark representations offside the route were not displayed transparently did not significantly undermine the shift of visual attention toward the route. We argue that visual attention was in both conditions distinctively affected by the task requirement of memorizing the route. Thus, most fixations in the non-transparent map were already relatively close to the route and not on landmark representations far offside the route. Applying transparency only narrowed the area of fixations around the route. This interpretation is supported by the fact that route memory performance did not differ significantly between the original map and the transparent map. Participant route memory performance seems to have relied primarily on reference points close to the route. Therefore, making reference points offside the route less visible and less likely to receive attention did not affect memory performance. However, performance differences could potentially occur if the task is carried out with more time pressure. If a task requires map readers to make quick decisions or to capture map information quickly, directing visual attention toward relevant map areas could reduce distraction from less task-relevant map areas. The effects of task requirements on the direction of visual attention are further investigated in the following chapter.

Taken together, the study demonstrates that visual salience affects the distribution of visual attention in predictable patterns and that these patterns can be manipulated by adjusting the map design. This makes it possible to direct visual attention toward specific task-relevant map elements. In future studies, it needs to be addressed how different ways of guided visual attention based on landmark pictogram and map design affect spatial tasks such as orientation and navigation, as well as the formation of mental spatial models.

### *8.4.3 Structural Salience*

Structural salience is a task- or context-dependent salience (Peebles et al. 2007). Previous research on structural salience focused primarily on the relative location of landmarks during navigation and the conceptualization of routes (Klippel and Winter 2005; Röser et al. 2011). Based on their relative location to the observer or a route, structurally salient landmarks can be divided into global and local landmarks (Elias and Paelke 2008).

Global landmarks in real-world settings are located far enough to only marginally change their relative location based on movements of the observer (Keil 2021). Thereby, they can act as beacons for assessing the general travel direction (Lynch 1960; Steck and Mallot 2000; Wenig et al. 2017). An important characteristic of a global landmark is its size, as it determines its remote visibility (von Stülpnagel and Frankenstein 2015). The distance from the observer can range between a few hundred meters (e.g., a tall building) and hundreds of kilometers (e.g., a mountain) or even light years (e.g., the north star). Global landmarks are not suitable to identify or memorize specific routes. Instead, they can be used to choose paths that lead to the general direction of the travel destination. This is reflected in a large flexibility of selected routes when people navigate based on global landmarks (Hurlebaus et al. 2008).

Local landmarks, on the other hand, are located close to the observer and/or to a specified route. Compared to local landmarks, global landmarks provide more precise information about the observer’s location and support encoding of and navigation along a specific route (Hurlebaus et al. 2008; Ruddle et al. 2011; Steck and Mallot 2000). Furthermore, they are frequently used for communicating routes (Anacta et al. 2017). Local landmarks can be subdivided based on their relative location to specific fragments of a route. They can be located close to decision points, potential decision points, or along the route (see Fig. 8.4). Decision points are intersections where the travel direction needs to be adjusted. Landmarks located at decision points can be used as a reference marker for identifying, memorizing, or communicating a required turn (Millonig and Schechtner 2007). Potential decision points are locations where the travel direction could be adjusted but should not be adjusted, for example, an intersection where the route follows a straight direction.

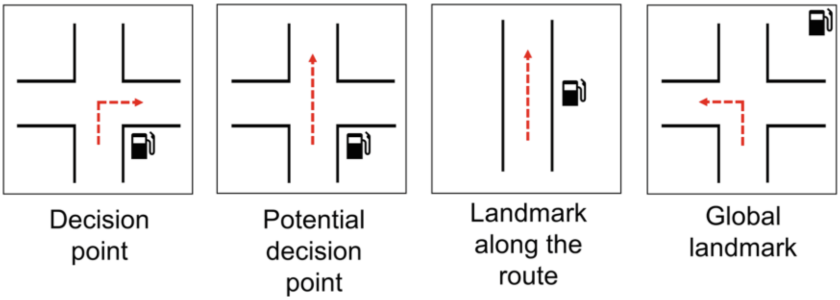

**Fig. 8.4** Navigation-oriented landmark locations. Local landmarks close to a route can be located at locations where the travel direction needs to be adjusted (decision point), at locations where the travel direction could be adjusted (potential decision point), or where the travel direction cannot be adjusted (along the route). Global landmarks act as beacons and are located offside the route (figure adapted from Bauer 2018)

Landmarks along the route are located next to the route where the travel direction cannot be adjusted (Anacta et al. 2017; Elias and Paelke 2008). Landmarks at potential decision points or along the route are not necessarily required for conceptualizing a route. However, they can be used during navigation to ensure that the route is still followed correctly (Millonig and Schechtner 2007). At decision points, landmarks can further be subdivided based on their location relative to the turn direction of a route. Röser et al. (2012) found that landmarks are more likely to be perceived and used in way finding and thus are more structurally salient, if they are located in the direction of the turn. Furthermore, turning decisions have been found to be more likely to be correct if a local landmark is available in the direction of the turn (Albrecht and Stuelpnagel 2018).

Similar to semantic and visual salience, the question of how structural salience affects the distribution of visual attention in maps has received little attention yet. As it has been argued that structural salience is task-dependent (Peebles et al. 2007), we carried out three studies on the effects of different map-based spatial tasks on the distribution of visual attention across the map. The first two studies investigated the structural salience of landmark representations in map-based route memory tasks (for the complete study details, see Keil et al. 2020a). In both studies, participants had to memorize routes displayed in maps obtained from OSM. Eye tracking was used to assess the distribution of visual attention across the maps. Landmark pictograms were available in the maps according to the locations of landmark representations added by volunteers to these OSM maps. However, to control semantic salience of pictograms, the original pictograms were randomly replaced by a set of OSM pictograms with similar levels of meaningfulness as measured in the first study of our project (see Keil et al. 2019). As other map elements than landmark pictograms could also be used as spatial reference points for memorizing the route, we also addressed how the visual complexity of a map (number of spatial elements) affects the structural salience of landmark pictograms.

Therefore, the first of the two route memory studies compared rural maps with a moderate number of map elements and urban maps with a high number of map elements. In the second study, only urban maps were used, but in one condition, fractions of the original map were used, and these fractions of the map were stretched to the original map size to create a second map condition with less map elements per map display. The second study was meant to address the limitation of the first study that landmark pictograms and other map elements are usually less evenly distributed across rural maps compared to urban maps. This was argued to affect the distribution of visual attention across the maps.

Both studies found distinctive effects of the task on visual attention. Most fixations were directed at map areas around the to-be-learned routes and toward decision points of the route. Map areas and landmarks offside the route were only rarely fixated (see Fig. 8.5). Thus, we found clear evidence for the effects a specific task has on the distribution of visual attention (as assessed using an eye tracker) across a map. Furthermore, the controlled manipulation of visual map complexity in the second experiment provided additional insights in the relevance of spatial reference points for the formation of mental spatial models. In the stretched maps with reduced spatial reference points, landmarks farther offside the displayed route were fixated. This indicates that not enough spatial reference points close to the route were available for the map users to memorize the route. Thus, participants seem to have expanded their search area for suitable spatial reference points.

The third study on the structural salience of landmark representations in maps addressed location memory tasks (for the complete study details, see Keil et al.

**Fig. 8.5** Fixations during a route-learning task. The fixation heat map demonstrates that visual attention was almost exclusively directed at the map areas around the to-be-learned route. Especially high fixation counts can be seen around landmark pictograms close to the route. These pictograms can be suggested to have a high structural salience. Maps were obtained from OSM (© OpenStreetMap contributors)

2020b). Participants were presented maps taken from the OSM project. The maps contained several landmark pictograms and a to-be-learned object location highlighted by a red pictogram. After a short distractor task, participants were presented the previously shown map again, but this time without the red pictogram. They were asked to click on the recalled location of the red pictogram using a computer mouse. During the encoding phase, fixations on landmark pictograms were recorded with an eye tracker (cf. Kuchinke et al. 2016; Dickmann et al. 2015).

The results of the third study on structural salience demonstrate how the task requirements of an object location memory task affect the structural salience of landmark pictograms in a map. According to these results, most visual attention was directed toward the landmark pictograms closest to the to-be-learned object location. Additionally, landmark pictograms were fixated more often if they were located closer to the (imaginary) horizontal and vertical cardinal axes of the to-be-learned object location (see Fig. 8.6). In agreement with assumptions of Rock (1997) and Tversky (1981), people appear to apply an imaginary coordinate system to perceived maps, either based on the viewing angle or the map borders. Landmark pictograms seem to receive privileged access to visual attention as spatial reference points if they are easy to conceptualize based on such an imaginary coordinate system, e.g., being directly above, below, left, or right to a to-be-learned object location.

Also, object location memory in this task was more accurate if the closest landmark pictogram was closer to the to-be-learned object location. Fixation rates steeply dropped toward the second- and third-closest landmark pictogram to the to-be-learned object location. Of interest is that there was no significant relation between the distance of these pictograms to the to-be-learned object location and the memory performance found in this study. This seems to indicate that a single landmark pictogram already can act as a spatial reference point for object location memory and that this task requirement directly affects (or better implies) the structural salience of this reference point and the low structural salience of other (potential) spatial reference points.

Taken together, the three studies provide new insights into the structural salience of landmark pictograms applying different map-based memory tasks. All three studies clearly indicate that task requirements affect how visual attention is distributed across maps. People appear to search for suitable reference points for memorizing locations or route nodes. Whether landmark representations are chosen as reference points depends on their distance and orientation relative to memorized locations and routes.

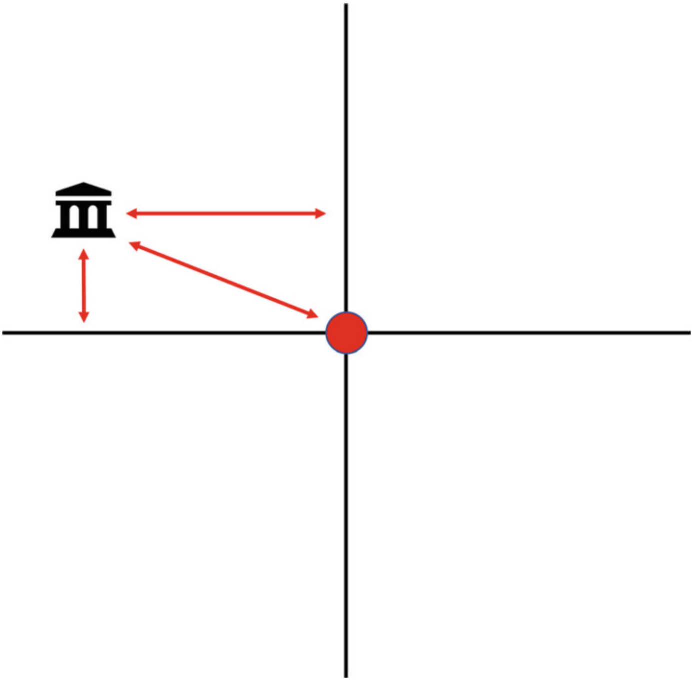

**Fig. 8.6** Structural salience in the context of object location memory. Landmark representations in maps were fixated more often when they were located close to a to-be-learned object location and its (imaginary) horizontal and vertical cardinal axes

## 8.5 Conclusion

The reported studies of the sub-project "The Effects of Landmarks on Navigation Performance in VGI-based Maps" of the SPP 1894 provide new insights in how landmark representations in maps are perceived and how they affect the formation of mental spatial models. Previous research on landmark salience primarily focused on the parameters that affect the direction of visual attention toward real-world landmarks (e.g., Golledge 1991; Klippel and Winter 2005; Millonig and Schechtner 2007; Röser et al. 2012). The studies reported in this paper extend these findings by investigating the salience of landmark representations in maps and depict similarities and differences between real-world landmarks and landmark representations in maps.

Semantic salience has been argued to affect the likelihood of real-world landmarks to attract visual attention both based on general attributes, as well as on individual characteristics of the observer. General attributes include cultural and historical significance, as well as the purpose or function of a landmark (Claramunt and Winter 2007; Nothegger et al. 2004; Raubal and Winter 2002; Röser et al. 2011). Individual characteristics consider emotional or knowledge associations of an observer with a perceived landmark (Golledge 1991; Nuhn and Timpf 2017; Quesnot and Roche 2015).

In the context of landmark representations in maps, semantic salience seems only partially based on the general attributes and the individual associations with the represented landmarks. Rather, the type of representation also needs to be considered. As landmarks are often represented in maps as pictograms, specific associations with a unique landmark can be overridden. For example, a famous church with a unique architecture could be represented by the same pictogram as every other church. Thus, the unique associations related to this church could not be evoked by only seeing its map representation. Furthermore, intercultural and individual differences can affect the ability to understand pictograms used to represent landmarks and, consequently, their semantic salience (Spinillo 2012).

Our first reported study demonstrated that, similar to real-world landmarks, visual attention toward landmark representations in the form of pictograms is affected by their semantics respectively their meaningfulness. However, opposed to approaches of defining semantic salience in advance (based on obtained knowledge), we found that landmark representations can also attract visual attention if the conveyed semantic information is more difficult to understand than that of surrounding objects. In other words, visual attention is not directed based on the intrinsic semantic characteristics of a landmark representation (where more meaningfulness equals more semantic salience and visual attention) but is in some circumstances also based on the semantic contrast to other objects.

However, how semantic landmark pictograms in interaction with different map designs affect the distribution of visual attention remains unclear and needs to be addressed in future studies. Interestingly, although semantic salience has been argued to be affected by individual characteristics (Golledge 1991; Nuhn and Timpf 2017; Quesnot and Roche 2015), our study found no pronounced individual differences in the perceived meaningfulness of landmark pictograms or the direction of visual attention toward specific pictograms. This demonstrates that, as mentioned above, individual associations with specific landmarks get lost when the landmarks are represented as abstract (generalized) pictograms. Still, as the study was carried out with a homogeneous cultural group, future research needs to address to what extent cultural background affects the semantic associations with specific landmark pictograms and, consequently, the direction of visual attention toward these map elements.

The role of visual salience for the selection of spatial objects as landmarks has been emphasized repetitively (Klippel and Winter 2005; Röser 2017; von Stülpnagel and Frankenstein 2015). A commonly mentioned criterion of visual salience is the visual contrast of an object to its surroundings based on its visual characteristics, for example, its size, color, or illumination (Clarke et al. 2013; Davoudian 2011; Duckham et al. 2010; Röser et al. 2011). We argued that the form of landmark representation in maps (usually as pictograms) overwrites the visual characteristics of a real-world landmark and thereby also its visual salience. However, due to their accentuated design relative to other map elements, landmark pictograms in maps are also visually salient and attract visual attention (see example in Fig. 8.5). This is reflected in their common use as spatial reference points, despite the availability of other potential spatial reference points in the maps (see Keil et al. 2020a,b). Furthermore, opposed to real-world landmarks, the visual contrast of landmark representations and other reference points in maps to surrounding map elements and, consequently, their visual salience can easily be modified. As demonstrated in our second study, adding transparency to specific map areas directs visual attention away from these areas. Thus, by manipulating map design according to task requirements, visual attention can be systematically directed toward relevant map areas and spatial reference points as landmark representations (though the effects on memory are in need of future research).

However, it needs to be considered that not only the inherent visual characteristics of landmarks and landmark representations in contrast to their surroundings affect their visual salience and, consequently, their likelihood to attract visual attention. The general ability to perceive landmarks and their representations in maps also needs to be addressed. Concerning the selection of objects as landmarks, Röser et al. (2012) and Klippel and Winter (2005) stress the relevance of visibility, thus the ability to perceive the object from a specific viewpoint. Spatial objects might be hidden behind other spatial objects. If this is the case, they cannot be used as landmarks, even if they have a high visual contrast to their surroundings. The visibility of landmark representations in maps, on the other hand, depends not on viewpoints in real-world space but on the displayed map region and the selection of landmarks to be represented in a map. Consequently, during map-based navigation, visual attention could be attracted by landmark representations in the map that are not visible from the user's viewpoint. This could impair navigation performance, as only visible landmarks can be used for self-localization. Therefore, future studies should address how visibility of landmarks can be assessed based on real-time tracking of map users and how this visibility information can be used to dynamically adjust which landmarks are represented in a map.

The third type of salience according to the approach of Sorrows and Hirtle (1999), structural salience, has been argued to be task- or context-dependent (Peebles et al. 2007). Landmarks have previously been argued to be structurally salient if they are located along a specific route and at locations that can be used to conceptualize a route (Klippel and Winter 2005; Millonig and Schechtner 2007; Röser et al. 2011). In three consecutive studies (see Keil et al. 2018, 2020a), we were able to demonstrate that, similar to real-world landmarks, landmark representations in maps are structurally salient based on their relative location to specific routes. The visualization of a task-relevant route directs visual attention to the map elements close to the route and its decision points. Furthermore, an additional study (Keil et al. 2020b) extended previous findings by demonstrating that landmark representations are also structurally salient and attract visual attention if they are located close to a to-be-learned object location and its (imaginary) cardinal axes. The effects of the cardinal axes of the map on the distribution of visual attention demonstrate a unique map-related characteristic of structural salience that cannot be applied to real-world space. Either based on the head orientation of the observer relative to a map or based on the (usually rectangular) shape of a map, up/down and left/right dimensions can induce such cardinal axes that are not induced by the perception of real-world space.

The reported findings emphasize the relevance of landmarks and landmark representations for location memory, as theorized by the mental spatial network of nodes and edges proposed by Werner et al. (2000). However, in contradiction to the allocentric mental spatial representation structure proposed by Werner et al. (1997, 2000), we found no evidence for a landmark configuration or framework used to conceptualize and memorize map space. In both the route memory and location memory tasks, visual attention was directed mainly toward the task-relevant landmarks close to the routes and object locations. Landmarks offside the routes and object locations received almost no visual attention. In the location memory task, already the second- and third-closest landmarks received significantly less visual attention, even if they were close to the to-be-learned object location. This demonstrates that participants did not explore the general spatial configuration of landmark representations. However, the lack of evidence in our experiments cannot be used to reject the assumption that landmark representations in maps are used to form a mental representation of maps based on nodes, as proposed by Werner et al. (2000). According to Millonig and Schechtner (2007), such allocentric mental spatial models are formed gradually during repeated interaction with spatial information. The short and clearly task-oriented perception of map information in our experiments might not have had sufficient power to detect or sufficient exploration time for the formation of an allocentric mental spatial model based on landmark configurations. In order to further explore the relevance of landmark representation configurations (landmark patterns) in maps on the formation of mental spatial models, future studies need to provide repeated interaction with maps and should be designed to support the formation of less task-specific mental spatial models, for example, by asking participants to draw sketch maps of the perceived maps. If, as assumed, landmark representation configurations are used as the first building block for the formation of mental spatial models (cf. Bestgen et al. 2017), identifying the ideal configuration characteristics and highlighting landmark representations in maps according to these characteristics could help to effectively and efficiently communicate spatial information to map users and support the formation of mental spatial models.

The reported studies provide first insight into salience characteristics of landmark representations in maps and their effects on the formation of mental spatial models. Based on these findings, better predictions of the distribution of visual attention across maps are possible. By systematically manipulating the salience of landmark representations, visual attention can be actively directed toward task-relevant map elements. The insights into the effects of directed visual attention on spatial tasks such as orientation or navigating along a selected route could be used to optimize automatic map generalization processes based on task requirements. In order to further exploit the potential benefits of the reported outcomes, future research needs to investigate how the systematic direction of visual attention toward specific map elements can improve performance on spatial tasks such as self-localization, orientation, and navigation in real-world environments. As a final step, the insights into the effects of directed visual attention on spatial tasks such as orientation or navigating along a selected route could be used to optimize automatic map generalization processes based on task requirements.

**Acknowledgments** This research was supported by the German Research Foundation DFG within Priority Research Program 1894 *Volunteered Geographic Information: Interpretation, Visualization and Social Computing* (VGIscience, Landmarks VGI, DI 771/11-1, KU 2872/6-1).

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