Elements of Geospatial Images to Support Cognitive Tasks in Wayfinding

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Abstract. Geospatial images, such as topographic maps and aerial photographs, have vastly increased in types, coverage and supply during the 21st century and these images are more and more used as sources of spatial knowledge for wayfinding. Usability research of the images has not followed the rapid development and many modern forms of geospatial images, such as panoramic street views, are insufficiently studied with regard to their usefulness for the users. In this paper, we present a study ensemble of three studies that address the usability of geospatial images for wayfinding using methods and previous results of spatial cognition research. A geo-image evaluation study, experimental 3D map rendering study, and eye-tracking study on elevation visualizations showed vertical and elevation information to be central for the acquisition of spatial wayfinding knowledge and resulted in an increased understanding about beneficial ways of representing elevations on maps using cartographic techniques.

Keywords: Geospatial image, Wayfinding, Elevation

1. Introduction

Geospatial images (abbr. geo-images), such as topographic maps and aerial photographs, often serve as an initial exposure to an unfamiliar environment for wayfinders, and so establish the basis of spatial knowledge used for navigation in the environment. The supply of easily available geo-images has exploded in the 21st century due to the rapid development of geospatial data acquisition and visualization techniques. For example, such previously occasional types of images as oblique aerial photographs and panoramic street views have become globally available in last ten years. However, the experimental research on the usability of the images in different tasks has not followed at the same pace. Particularly, the extensive research and methods of spatial cognition have not yet been comprehensively considered when addressing the users' needs although clear empirical evidence from this research field is available: at least the vantage point of the image (e.g. Fontaine 2001) and degree of realism (e.g. Meijer et al. 2009) have been shown to have effects on wayfinding performance. For instance, three-dimensional cartographic maps, oblique aerial photographs, and panoramic street views remain under-investigated from the cognitive perspective.

The gap between the technological development and cognitive suitability of geospatial images is addressed in the present article by summarizing an ensemble of three studies that investigated the support of various elements of geo-images for the human acquisition of spatial knowledge in wayfinding environments:

1. Geo-image evaluation study (Kettunen et al. 2012);
2. Experimental 3D map rendering study (Kettunen et al. 2009); and
3. Eye-tracking study on elevation visualizations (Putto et al. 2014).

Section 2 overviews relevant literature, *Section 3* introduces the employed methods and *Section 4* presents the acquired results. *Section 5* discusses the outcomes of the studies and *Section 6* draws conclusions.

2. Litterature

2.1. Spatial knowledge

Wayfinding is essentially dependent on *spatial knowledge* about physical environments that is necessary already for the definition of a wayfinding task and that then makes planning and traversal of routes possible (Kuipers 1978). Traditional research on spatial knowledge has concentrated on the acquisition of knowledge from direct experience in the environment (Downs and Stea 1973) but geospatial images certainly make at least as important a source of spatial knowledge for wayfinding. Independent of the source, spatial knowledge is known to consist of three fundamental forms of knowledge (Siegel and White 1975):

1. *Landmark knowledge* is information for identifying landmark features that enables place recognition. It is mostly acquired in the visual form and maintained in the visual recognition memory;
2. *Route knowledge* is sequential information about paths and surrounding landmarks that allows people to conduct basic wayfinding along a certain route from one place to another; and

3. *Configuration knowledge* (or *survey knowledge*) is structured information about features and their locations in the environment that makes the understanding of environmental patterns possible and enables advanced operations of spatial cognition, such as planning shortcuts or completely new routes.

Landmarks are the atomic concept of Siegel and White's (1975) model of spatial knowledge but they have also been studied by many other researchers (see Richter and Winter 2014) and their importance has been verified both through behavioral (e.g. Denis 1997) and neuroscientific studies (e.g. Janzen and van Turennout 2004). Thus, landmark knowledge is central for the success of wayfinding also when the knowledge is acquired from geo-images, on which this paper focuses.

2.2. Visualization of elevations

Visualization of elevation information on two-dimensional maps has traditionally widely relied on contour lines, particularly so in topographic maps. Contour lines depict points of equal elevation on the ground and their intervals allow for accurate estimation of elevation differences on a map (Imhof 1965/1982). Contours allow for rapid reading of elevations and confidence of use (Wilkening and Fabrikant 2011) but they may cause difficulties of interpretation among less experienced map readers (Lobben 2004).

Equal elevations can also be visualized using hypsographic coloring with which color-coding is draped on a map to represent surfaces inside specific elevation intervals (Imhof 1965/1982). Hypsographic coloring enables easy viewing of distribution of elevations on a whole map image.

Relief shading is an efficient means to create an intuitive 3D impression on a 2D map by imitating reflection of light on the terrain (Imhof 1965/1982). Hill or slope shading or both may be used with one or multiple light sources. Map readers often tend to find relief shading appealing to look at, but it has turned out to be difficult to use for accurate estimations of elevation (Wilkening and Fabrikant 2011).

Three-dimensional drawing produces realistic depictions of elevations and tall objects. In computational 3D rendering, three-dimensional geodata is required and selection must be made between photorealistic and cartographic approaches. Cartographic 3D rendering is characterized by the common factors of cartography: selection, generalization and symbolization of the visualized physical features (International Cartographic Association 2003) and can result in much more communicative environmental representation than photorealistic 3D rendering (Döllner 2007).

Three-dimensional rendering typically requires multiple rendering parameters. Viewing projection is one of the most central of these parameters although perspective projection is typically unconsciously selected. A cartographically convenient alternative is the oblique parallel projection that provides good depiction of landforms, possibility to measure distances on equal elevation surfaces and readability by sections throughout the map (Jenny and Patterson 2007). For rendering parameters, Jenny and Patterson suggest south-west lighting, small scale and vertical exaggeration.

2.3. Eye tracking on maps

Map reading is a potential but challenging subject for eye tracking due to the detailed visual complexity of maps and intensive cognitive processing while reading them. Early eye-tracking studies on maps date back to 1970s (see Steinke 1987), but only recent tools and methods have provided sufficient accuracy for analysing map reading close to the symbol level (Brodersen et al. 2001). Eye movements convey information on the attention of the viewer and the cognitive complexity of the view. They are typically measured by durations of fixations and amplitudes of saccades that depend on the difficulty of the task (Rayner 2009).

3. Methods

The summarized ensemble of three studies investigated the human acquisition of spatial knowledge for wayfinding from geospatial images. Each study approached the topic from different perspective using separate methods that are presented below.

3.1. Geo-image evaluation study

In the geo-image evaluation study, general factors or *image parameters* of wayfinding support in geo-images were itemized based on a thorough literature review about spatial knowledge (see Kettunen et al. 2012). Three image parameters were identified that formed an evaluation framework used for evaluating geo-images with regard to their support for the acquisition of spatial knowledge (for examples of parameters, see Kettunen et al. 2012):

1. *Vantage point* refers to the three-dimensional viewpoint of a geo-image. Three key cases were identified in the study: *aerial vertical, aerial oblique* and *ground horizontal* vantage points;
2. *Number of visible vertical features* refers to the quantity of perceptible vertical faces of objects in a geo-image and can vary continuously between non-existent and comprehensive cases. It relates both

to the vantage point of the image and to the inclusion of vertical dimension in the geodata on which the image is produced; and
3. *Visual realism* refers to how closely a geo-image resembles the real visible world and can vary between fully abstract and fully photorealistic cases.

Using the three image parameters, seven common types of geo-images in wayfinding activities were evaluated (*Table 1*) and their support for the acquisition of spatial knowledge addressed.

3.2. Experimental 3D map rendering study

In the experimental 3D map rendering study, an oblique parallel view was composed in order to find intuitive and useful ways for depicting terrain relief three-dimensionally on a geospatial image (see Kettunen et al. 2009). Four factors of rendering were experimented with:

1. *Oblique parallel projection* is a viewing projection that makes it possible to render constant scale throughout a geo-image simultaneously with rendering a slightly occluded terrain relief (Jenny and Patterson 2007);
2. *Directed lighting* can create a three-dimensional relief effect on a geo-image. The horizontal lighting angle defines which sides of objects are illuminated and the vertical lighting angle affects the brightness of shading on the image and so the visibility of terrain details;
3. *Hypsographic coloring and contours* facilitate the measurement and interpretation of terrain elevations in geospatial images.

Geo-image type	Vantage point	Number of visible vertical features	Visual realism
Symbolic 2D map	aerial vertical	non-existent	abstract
Aerial orthophoto	aerial vertical	low	photorealistic
Tilted 2D map	aerial oblique	non-existent	abstract
Oblique aerial photo	aerial oblique	high	photorealistic
Oblique 3D drawing	aerial oblique	high	low
Panoramic street view	ground horizontal	comprehensive	photorealistic
Ground-level 3D rendering	ground horizontal	comprehensive	high

Table 1. Image parameters of the evaluated geo-images (for examples of geo-image types, see Kettunen et al. 2012).

4. Hypsographic color-coding is often applied using green-to-brown scale and complemented using contours with smaller elevation intervals; and
5. *Equilateral and equiangular grid* has the lengths of grid segments and the angles between the segments equal. Three kinds of such grids exist: square, triangular and hexagonal grid. These can provide a useful graphic metric reference for a geo-image to support easy visual approximation of distances, directions and surface areas on a geo-image in which the scale is deformed due to projections.

The oblique parallel view was rendered using the 3D terrain modelling software Natural Scene Designer Pro 5.0 and a high-accuracy digital elevation model from a laser scanning of a southern Finnish national park area (resolution 1 m, elevation accuracy 20 cm; Sarjakoski et al. 2007).

3.3. Eye-tracking study on elevation visualisations

In the eye-tracking study, three types of topographic map images were investigated in order to investigate how different elevation visualizations affect map viewing (*Figure 1,* see Putto et al. 2014):

1. *Contour lines* with 5 m intervals and wider index lines in every 20 m with elevation labels;
2. *Relief shading and contour lines* using slope shading (Oksanen et al., 2011); and
3. *Oblique parallel view* similar to the one in the experimental 3D rendering study but with topographic map at the base.

Three map-viewing tasks were given to 26 student participants who had not been educated in geographic sciences. The participants were divided into three groups that each viewed a different map image type with the same tasks in the same order:

1. *Visual search* for an abstract pentagon symbol (39 map images);
2. *Area selection* and drawing of an area where one would like to go hiking (8 map images); and
3. *Route planning* and drawing of a truly realizable route between marked points (8 map images).

The collected response time and eye movement data were analyzed using non-parametric statistical tests: Kruskal-Wallis and pair-wise Wilcoxon rank-sum tests using Bonferroni corrections for comparisons between groups (map image types), and Friedman rank and Wilcoxon matched-pairs signed-rank tests for comparisons between tasks (within participants). Spearman correlations were calculated for examining relationships between response time and eye-movement measures.

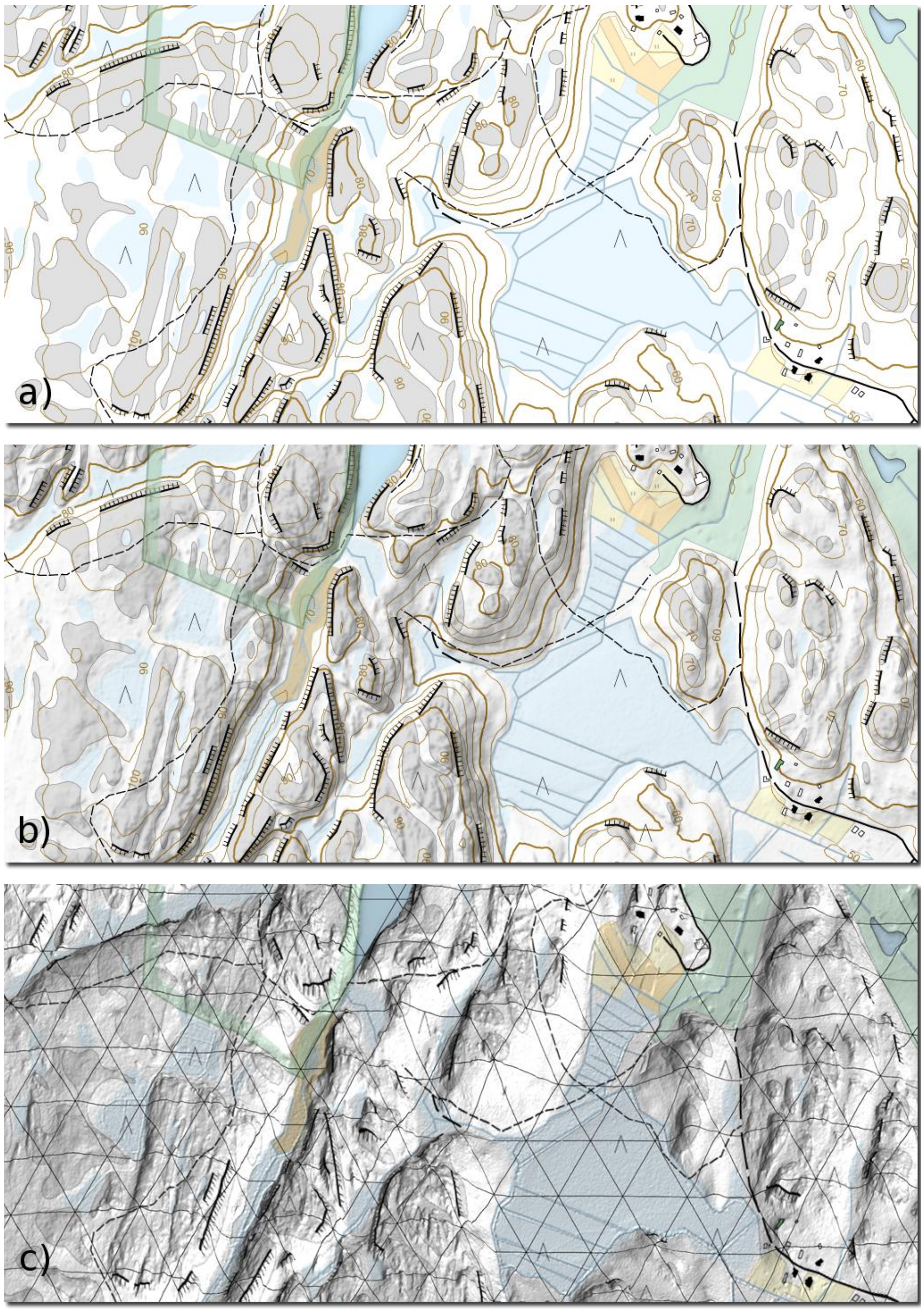

Figure 1. Examples of map images with different elevation visualisations in the eye-tracking studies.

4. Results

4.1. Geo-image evaluation study

The evaluation of the seven commonly used geospatial image types resulted in a literature-founded theoretical and empirical understanding of the support for the landmark, route and configuration types of spatial knowledge for each image type (see Kettunen et al. 2012). As a general founding, geo-images with aerial oblique vantage point give the strongest support for the acquisition of spatial knowledge for wayfinding: landmark, route and configuration knowledge can all be gained efficiently from a single image.

With regard to single types of knowledge the results are different. Landmark knowledge is supported most by panoramic street views and ground-level 3D renderings in which landmarks can be seen in a detailed way. Route knowledge is best acquired from the oblique aerial photos that show both the structure of the route and the surroundings of decision points. Configuration knowledge is most supported in symbolic 2D maps and oblique 3D drawings that can provide a rapidly interpretable and comprehensive view on the structure of the environment while simultaneously representing the most essential landmark features for wayfinding.

Particular experimental findings about the support of spatial knowledge of geo-image types from the literature are presented in *Table 2*. Several image types lack reliable experimental evidence on their support for acquiring spatial knowledge.

4.2. Experimental 3D map rendering study

The composition of the oblique parallel view resulted in a view shown in *Figure 2*. The experimental optimization of elements for the view resulted in the following configurations (see Kettunen et al. 2009):

1. *Oblique parallel projection* with vertical viewing angle 23° allows for a three-dimensional impression due to a small occlusion of back-facing slopes. Horizontal viewing angle 180° (towards north, fixed by the software);
2. *Directed lighting* with horizontal lighting angle to the south-east (light towards north-west) illuminates the prolonged southern slopes in the view and fits with the direction of hills in the terrain. Vertical lighting angle 25° provides a well-suited brightness for depicting terrain details in the view;

Geo-image type	Experimental findings from the literature
Symbolic 2D map	• Rapid acquisition of accurate spatial knowledge (e.g. Oulasvirta et al. 2009, Waller et al. 1998) • Challenging interpretation of symbols (e.g. Sjölinder et al. 2005)
Aerial orthophoto	• Preferred to street photos in route planning and navigation (Hile et al. 2008)
Tilted 2D map	• No explicit experimental results found
Oblique aerial photo	• No explicit experimental results found
Oblique 3D drawing	• Effective for wayfinding in complex built environments (Fontaine 2001) • Preferred to photorealistic 3D rendering (Plesa and Cartwright 2008)
Panoramic street view	• Mostly used at decision points (e.g. Hile et al. 2008)
Ground-level 3D rendering	• Mostly used for landmark features (Oulasvirta et al., 2009) • Difficult to steer the view (Oulasvirta et al. 2009, Sjölinder et al. 2005, Waller et al. 1998)

Table 2. Experimental findings in the literature on the wayfinding support in the evaluated geo-images.

3. *Hypsographic coloring* with green-to-brown color scale in 10 m elevation intervals produces sufficient elevation information with five elevation classes in the depicted terrain; and
4. *Equilateral and equiangular grid* in triangular form depicts distances, directions and projection deformations illustratively. Segment length 50 m provides a sufficiently dense grid without interfering too much with the underlying map image.

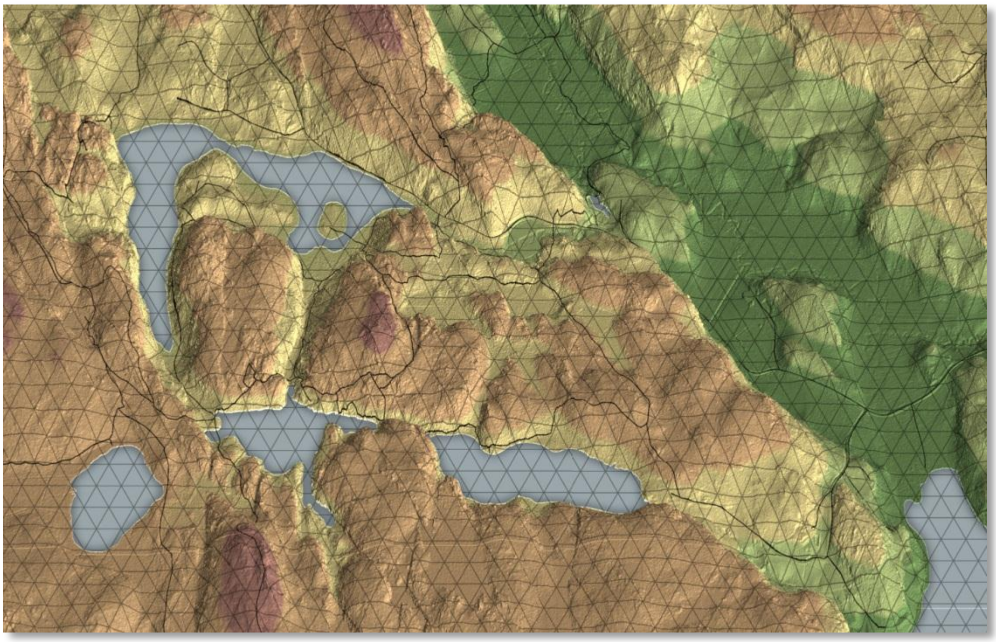

Figure 2. The experimental 3D map rendering using oblique parallel projection, hypsographic coloring and triangular grid (segment length 50 m).

4.3. Eye-tracking study on elevation visualisations

Statistically significant differences in response times and eye-movement measures were found between elevation visualisations in the eye-tracking study (*Table 3*, see Putto et al. 2014). Notably, no significant differences occurred in the area selection or route planning tasks but several were found in the visual search task.

According to the fixation durations and saccade amplitudes of eye movements, the oblique parallel view appeared different to look at compared to the two other map images. The elevated number of fixations with the oblique parallel view correlated highly with response times (correlation $\rho = 0.956$).

Experimental measure	**Visual search task**
Response time	Oblique parallel projection > Contour lines
Number of fixations	Oblique parallel projection > Contour lines
Fixation durations	Contour lines > Relief shading

Table 3. Statistically significant differences in the measures between elevation visualisations.

5. Discussion

The ensemble of the presented studies highlighted the importance of vertical and elevation features in geospatial images for wayfinding and the need to carefully design the visualization of geo-images in order to fully support the acquisition of spatial knowledge.

In the geo-image evaluation study, the literature-based evaluation framework encapsulated theoretical and empirical knowledge about the supportive factors of geo-images for wayfinding and provided heuristics for evaluating pedestrian wayfinding support in geo-images. The evaluations of common geo-image types showed important variation between the support of the image types for spatial wayfinding knowledge dependent on the selected image parameters. Geo-images representing three-dimensional data from the aerial oblique vantage point were evaluated most supportive because of their ability to transfer the crucial landmark knowledge simultaneously with route segments and overall structure of the environment. According to the literature review, many modern types of geo-images lack experimental studies addressing their cognitive characteristics and usability in wayfinding, which should be addressed with additional research by, for example, the experts of cartography.

The experimental 3D map rendering identified convenient rendering parameters for producing a cartographically appropriate three-dimensional map with the aerial oblique vantage point that was found beneficial in the geo-image evaluation study. The parameters were found to be highly dependent on the terrain under visualization. The eye-tracking evaluation showed the challenges of developing such a 3D map: the participants spent much time and fixated intensively at the oblique parallel view, which indicated high cognitive load while watching the view. The triangular grid and relatively dark relief shading probably caused the most extent of the complexity of the oblique parallel view by increasing visual clutter to the view (e.g. Fabrikant et al. 2010). Similar increase in the number of fixations as a function of map complexity has been observed also previously (Brodersen et al. 2001).

In the eye-tracking study, relief shading was found the most beneficial of the evaluated elevation visualizations. According to the response and fixation times as well as saccade amplitudes, sole contour visualization was cognitively heavier and the oblique parallel view was particularly challenging in the search task. However, the oblique parallel view allowed for the best results in the area and route selection tasks requiring free viewing, which reflects the cartographic potential of the view. Hence, the oblique parallel view should be further developed and its strong relief impression experimented with in order to fully address its usability in visualizing elevation.

6. Conclusions

The presented study ensemble addressed the factors of acquisition of spatial knowledge from geospatial images for wayfinding with an aim to employ the extensive research on spatial cognition for evaluating and enhancing the usability of geo-images.

The geo-image evaluation study formed an evaluation framework for assessing the support for spatial knowledge in geo-images and found that geo-images with aerial oblique vantage point are particularly advantageous although variation is wide between the support of geo-image types for different kinds of spatial knowledge.

The experimental 3D rendering study pointed out convenient parameters for rendering 3D terrain maps and showed the dependency of parameters on a particular terrain. The eye-tracking study brought up challenges in rendering such a view with appropriately low level of visual clutter. A 2D relief-shaded map appeared to provide the best measures in the eye-tracking study, but the oblique parallel view performed also well in the free exploration tasks and should be studied further. The eye-tracking method was found convenient for evaluating the readability of maps, and more eye-movement studies should be conducted on map images.

Overall, these studies underline that spatial cognition research is crucial in heading cartography for ever more satisfying user experience of maps (see also Kettunen 2014).

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