Empirical construction of a landmark ontology for wayfinding in varying conditions of nature

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Abstract

Route guidance in navigators is proceeding towards landmark-based instructions that research on spatial cognition has shown to be most efficient for guiding human wayfinding. We conducted an empirical study ensemble of four think-aloud experiments with 42 participants in order to collect reliable sets of landmarks to be used in such a navigator in varying conditions of Nordic nature. In this paper, we report an aggregated analysis of these experiments that took place in summer, winter, day and night. We created an ontology of the landmarks perceived by participants, together with their observed usefulness in different conditions. We identified sets of especially perceptible landmarks in all and in certain conditions, and found clear differences in landmark perception between the conditions. The resulting formal ontology can be used for implementing navigators to be used in nature with highly personalised navigation.

Keywords: landmark, perception, ontology, wayfinding, nature, navigator

1 Introduction

The development of navigators is proceeding towards landmark-based navigation instructions in concordance with the research of spatial cognition that considers landmarks to be the basement of human spatial knowledge [13, 16]. Use of landmarks in route instructions has been shown to improve the navigation accuracy and performance when compared to geometric instructions that are mostly used in navigators today [14]. In order to build useful and effective landmark-based navigators, suitable landmarks must be known, based on which the users can easily perform instructed route actions, such as "take the stairs on the left of the knoll". Suitable landmark types vary depending on, for example, the type of surroundings, weather and terrain conditions, locomotion modality as well as on the experience and preferences of the user.

This paper presents an aggregated analysis of our studies for the collection of useful landmark concepts for pedestrian wayfinding instructions in nature [5, 6, 15]. We report compound results that are additional to the previous analyses. We collected landmark concepts empirically in on-route experiments in varying conditions of nature: summer and winter (season study) as well as day and night (time-of-day study). We counted and categorised the concepts in order to find the most easily perceptible landmark types for route instructions. Eventually, we placed the landmark concepts in a context-sensitive formal ontology that can be used to implement a landmark-based navigator for nature routes.

2 Related research

Landmarks have long been regarded as the basic concept of human spatial cognition. Lynch [10] introduced the concept as a remarkable point-like feature in the environment that people utilise for understanding space. Siegel and White [16] presented a focal model of types of spatial knowledge: landmark knowledge establishes the foundation for the development of route and configuration knowledge types. Later research has consolidated the centrality of landmarks for all spatial knowledge [2] and shown their importance not only at the reorientation and decision points of routes [1, 3] but also between the decisions points as reassuring references [9].

Most of the empirical landmark studies have been conducted in urban environments and only few in nature that sets particular challenges for both an individual to acquire valid spatial knowledge and a researcher to organise experiments. Whitaker and Cuqlock-Knopp [18] found nature wayfinding experts refer most often to manmade cues, then elevations and water, as well as vegetation landmarks when describing their personal navigation experiences. With regard to particular wayfinding conditions in nature, Rehrl and Leitinger [12] studied ski tourers' landmark descriptions, in which they found landforms to be the clearly most used landmark type. Kumagai and Tack [9] carried out a wayfinding study in night time nature, with the help of night-vision goggles and found that participants observed targets significantly worse at night than by day.

A few studies have investigated landmarks in nature using photographs. Snowdon and Kray [17] asked participants to name hike-supportive landmarks in photographs and collected the most frequently mentions of peaks and water courses, followed by woods, rocks, lakes and landforms. The participants of Le Yaouanc et al. [8] commonly named footpaths, lighthouses and oceans in shown panoramic photographs of nature.

Ontologies are used to model human knowledge to be utilised for computational processing, and this also applies to human spatial knowledge. Cartographers present ontologies in maps [4] and geoscientists model landmark ontologies in geodatabases. To take an example of ontological modelling of spatial knowledge: Paepen and Engelen [11] built ontologies for modelling pedestrian navigation. Their ontologies showed that pedestrians need much more detailed information for wayfinding than, for example, car drivers.

Due to the lack of studies considering nature as environment and empirical construction of landmark ontologies, we present one such study ensemble in the following.

3 Collection of landmark concepts

3.1 Arrangements of the experiments

We collected landmark concepts in summer, winter (daytime), day and night (summertime) think-aloud experiments along nature trails in two similar forested recreational environments in southern Finland. The routes ran on footpaths and outdoor tracks, and their lengths were 1.2 km in the season study and 1.3 km in the time-of-day study, taking approximately half an hour to walk through. If snowfalls preceded the test sessions in the winter experiment, the experimenters walked through the route in advance in order to make the path network equally visible for all the participants.

A total of 42 persons took part in the studies: 10 in the summer, 10 in the winter experiments and 11 in the day, 11 in the night experiments. The participants were of all ages and mainly technology researchers and outdoor club members. Their age, nature experience, region knowledge and spatial abilities according to the Santa Barbara Sense Of Direction Scale (SBSOD) did not differ between the groups within studies ($p>0.19$ in the two-tailed Wilcoxon rank-sum tests).

The participants first filled in demographic and SBSOD (time-of-day study only) questionnaires, after which we gave them the think-aloud task assignment. The assignment for the season study was: "Describe everything that you find remarkable in the surroundings and explain their locations. Stop when you have to make a decision about which route to take. Describe the options in detail." This led participants easily to unfocused descriptions, so we modified the assignment for the time-of-day study, in which we gave two assignments in different parts of the route, targeted at memorising the route: "Walk a route with the experimenter and memorise the route so that you are able to 1) walk through it again without guidance 2) describe it to another person who is to walk through the same route". We asked the participants to follow the trail under feet. In case of uncertainty, the experimenter following the subject would point out the way. The participants made a 2–3 min think-aloud exercise before the actual route traversal task.

The participants did not use any navigational aids. They carried an audio recorder and a 900 lumen headlamp in the night experiment. The experimenter recorded video while walking after the participant.

3.2 Extraction of landmark concepts and groups

We extracted landmark concepts from the think-aloud protocols using the methods of natural language processing. Each permanent and perceptible feature mentioned by the participants was regarded as a landmark according to the common definition of a landmark in spatial cognition research [1, 14]. The definition of landmarks in the transcripts was made by groups of researchers in order to reduce subjectivity. The extraction proceeded as follows:

1. Transforming inflected words into the basic form (Helsinki Finite State Transducer HFST);
2. Manual choosing of landmark words from the list of all words (Python scripts, Natural Language Toolkit NLTK);
3. Checking that the landmark words were really used for denoting landmarks (string searches in the transcript files);
4. Putting landmark word synonyms together into landmark concepts (manual work);
5. Recognising bigrams that the participants used as landmark concepts, such as "fallen tree" (the two words preceding and the two words following the landmark words in the transcripts, Python scripts, NLTK);
6. Categorising the landmark concepts into as homogeneous groups as possible: "Structures", "Passages", "Trees and parts of trees", "Waters", "Land cover", "Rocks", "Signs" and "Landforms" (manual work); and
7. Counting of the landmark concepts and groups in the transcripts (Python scripts, NLTK).

3.3 Results of landmark concepts and groups

The extraction of landmark concepts and groups resulted in precise counts of their relative frequencies in the think-aloud protocols. We listed the most frequently used landmark concepts by experiment and identified the concepts that were top-listed in all experiments as particularly useful ones for route instructions: "fallen tree", "route mark", "footpath" and "bridge" (Table 1). We also gave particular attention to those landmark concepts that were mentioned by every participant in each experiment and more so if a landmark concept occurred in multiple of these lists, such as "bridge" (Figure 1). In addition, landmark concepts that were repeatedly mentioned in one condition only were collected (Table 2), as well as those that had significant statistical difference in use frequencies between experiments in a study (Table 3).

The frequencies of landmark groups show the level of presence of landmark types along the two routes but also overall high-ranking landmark groups that are especially useful in route instructions: "Structures", "Passages" and "Waters" at least (Figure 2). Statistical differences between conditions occurred for two landmark groups in each study and advise the use of these landmark groups in different conditions. Of interest were also those landmark groups that some participants did not mention at all in some conditions (Table 4).

Table 1: The 15 most frequently mentioned landmark concepts in each condition. *Boldface* denotes the landmarks that were in top 15 in all conditions.

Rank	SUMMER	Lmf[a]	WINTER	Lmf[a]	DAY	Lmf[a]	NIGHT	Lmf[a]	Rank
1	***road***	9.49%	house	8.86%	***road***	13.29%	***route mark***	13.74%	1
2	house	7.44%	creek	7.09%	***route mark***	9.11%	***road***	11.06%	2
3	spruce	6.35%	lake	6.47%	river	7.07%	river	5.08%	3
4	lake	6.28%	spruce	6.02%	***fallen tree***	6.22%	signboard	4.60%	4
5	creek	5.77%	parking lot	5.49%	info board	4.77%	***fallen tree***	4.26%	5
6	parking lot	5.64%	***route mark***	4.07%	hill	4.34%	hill	3.91%	6
7	footpath	5.19%	***road***	3.90%	footpath	3.58%	outdoor track	3.85%	7
8	birch	3.40%	birch	3.54%	outdoor track	3.41%	info board	3.43%	8
9	***fallen tree***	3.14%	***fallen tree***	3.45%	signboard	3.15%	spruce trees	3.30%	9
10	crossing	3.01%	spruce trees	3.45%	hillside	2.81%	bare rock area	3.16%	10
11	cliff	2.88%	uphill	3.37%	boat shore	2.73%	hillside	3.16%	11
12	***route mark***	2.82%	ditch	2.92%	underpass	2.64%	underpass	2.75%	12
13	marked passage	2.76%	pine	2.66%	spruce	2.64%	footpath	2.68%	13
14	boulder	2.63%	footpath	2.39%	bridge	2.64%	boulder	2.68%	14
15	ditch	2.50%	guidepost	2.39%	water	2.64%	bridge	2.47%	15

[a] Landmark frequency = Landmark count / Total landmark count (within a condition)

Table 2: Landmark concepts mentioned repeatedly in only one condition. Landmarks are presented in the decreasing order of frequency.

SUMMER	WINTER	DAY	NIGHT
1. pit	1. witch's broom	1. water slide	1. pine tree
2. marsh		2.graffiti	2. coniferous trees
		3. leaning tree	3. tall grass
		4. courtyard	4. shrubbery
		5. slope ramp	5. goat willow
			6. flat
			7. boulder field

Table 4: Landmark groups that some participants did not mention at all.

SUMMER	WINTER	DAY	NIGHT
Landforms	Passages	Rocks	Rocks
	Land cover	Signs	

Figure 1: Landmarks mentioned by every participant in an experiment. *Emphasised* if mentioned in both the studies.

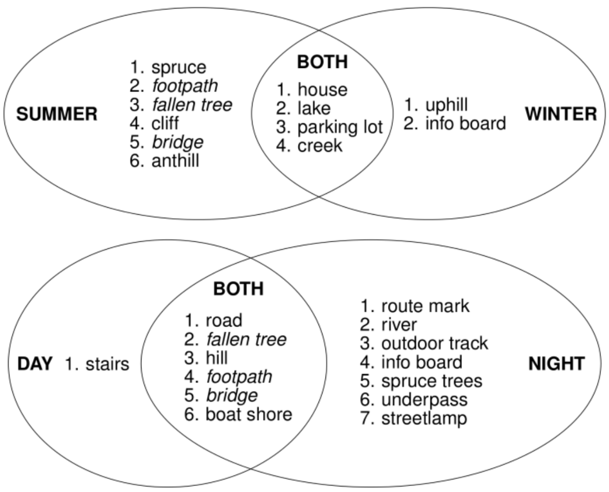


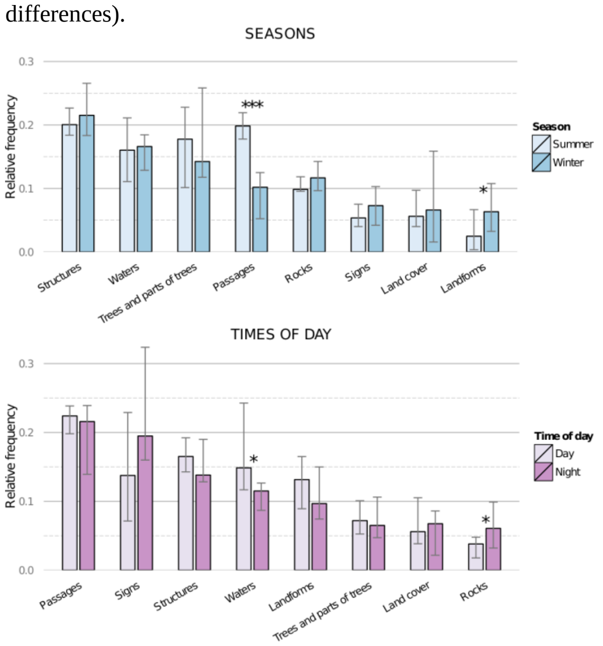
Table 3: Repeatedly mentioned landmarks in one condition only.

SEASON STUDY	High cond [a]	Lmf diff [b]	TIME-OF-DAY STUDY	High cond [a]	Lmf diff [b]
footpath	summer	2.8 pps	footpath	day	0.9 pps
crossing	summer	1.7 pps	boulder	night	1.9 pps
anthill	summer	1.2 pps	standing rootstock	night	1.2 pps
shore	summer	0.8 pps	streetlamp	night	0.9 pps
uphill	winter	2.4 pps			
house	winter	1.4 pps			
railing	winter	0.6 pps			

[a] Condition in which the landmark frequency was significantly higher

[b] Median difference among participants in the landmark frequency between conditions

Figure 2: Relative frequencies of the landmark groups in conditions (median, 95% confidence intervals, significant differences).



4 Creation of the landmark ontology

Construction of the formal landmark ontology began with placing the extracted landmark concepts and groups from the transcripts of the season study into classes of a two-level taxonomy using the Protégé ontology editor. Next, mid-level classes were inserted in between as necessary to gather particularly similar landmark concepts under descriptive classes. In order to achieve a more complete ontology, landmark concepts from legends and specifications of the topographic and orienteering maps were added on top of the empirically collected landmarks [see 15]. Eventually, new landmark concepts from the time-of-day study were inserted into the taxonomy.

The resulting ontology contains 115 bottom-level and 34 middle-level named classes in the 8 top-level landmark groups. The depth of the ontology is five levels, including the top class "hikingLandmark".

The changing conditions in nature were inserted in the ontology by using a simple three-level taxonomy that includes four named classes for the conditions in the studies (summer, winter, day and night). The knowledge acquired through the studies on the perception of landmarks in the conditions was incorporated into the ontology by using object properties and defined classes. Two object properties were defined:

- **isEasilyPerceptibleLandmarkInCondition**: landmark mentioned by every participant of a condition or statistically significant frequency of use compared to the other condition of a study; and
- **isHardlyPerceptibleLandmarkInCondition**: landmark used in the other condition of a study only.

With the aid of an ontological reasoner (Hermit 1.3.7 in the Protégé), the landmark classes denoted by object properties were gathered together into eight defined classes as listed in the following (increasing order of frequency for "easilyPerceptible..." and decreasing for "hardlyPerceptible..."):

- **easilyPerceptibleSummerLandmark**: footpath, crossing, fallenTree, cliff, bridge, anthill;
- **hardlyPerceptibleSummerLandmark**: witchsBroom;
- **easilyPerceptibleWinterLandmark**: railing;
- **hardlyPerceptibleWinterLandmark**: marsh, pit;
- **easilyPerceptibleDayLandmark**: footpath;
- **hardlyPerceptibleDayLandmark**: [no landmarks];
- **easilyPerceptibleNightLandmark**: routeMark, river, outdoorTrack, infoBoard, spruceTrees, streetlamp, standingRootstock; and
- **hardlyPerceptibleNightLandmark**: slopeRamp, leaningTree, courtyard.

The landmark ontology constructed in this study was formalised in the Web Ontology Language (OWL) format, which fits particularly semantic efforts and can be later implemented in navigators by using appropriate parser software. A graphical representation of the ontology can be viewed at http://www.fgi.fi/fgi/research/landmark-ontology.

5 Discussion and conclusions

The empirically based ontology created through the presented study ensemble contains nature landmarks and their relationships with regard to seasons and times of day in a formal description that can be used for building context-sensitive navigators to be used in nature. Landmarks in the ontology represent primarily Nordic forested recreational environments from a hiker's perspective, but the most highlighted landmarks are certainly useful also in other kinds of environments in nature. The created ontology is the first of its kind in considering the in situ perception of routes in nature and itemising both the individual landmarks as well as landmark types (groups) in a comprehensive way. The method for constructing the ontology can be utilised for any kind of environment and such use would be beneficial for verifying and developing the method further.

The present results on useful nature landmarks for wayfinding elaborate and support the few previous landmark study results in nature. We found structure landmarks to be highly frequently perceived in nature, although they were rare in the environment compared to other landmark groups. A similar result also occurs in the studies of Whitaker and Cuqlock-Knopp [18] and Le Yaouanc et al. [8]. Passage landmarks were another widely perceived landmark group, much because they framed the travelled trail. However, Le Yaouanc et al. [8] found a similar result. In addition, water landmarks have been also previously identified to be easily perceptible in nature [8, 17, 18].

Observed differences in the perception of landmarks and landmark groups between conditions resulted mainly from seasonal changes of vegetation, snow cover and lighting that affected the visibility of landmarks. A particular exception was illuminated features that could be used as global landmarks at night, such as the frequently mentioned "streetlamp". The resulting ontology effectively takes into account the observed differences and can help greatly in creating reliable route instructions in specific conditions of nature.

In future, the presented work should be continued by deepening the analysis to individual landmarks and the landmark ontologies of individual persons studied for considering the possibility to make navigation instructions personalised. Similar landmark experimentation and ontology creation could also be arranged in other kinds of noteworthy environments and conditions, such as urban environments at night.

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