Acquisition and Cartographic Applications of Subjective Geodata

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Abstract. Most geospatial applications provide services based on objective, physical parameters. However, humans interpret locations subjectively. By doing so, subjective spatial relations towards space are developed, which in turn, affect decision-making and behavior in space (e.g. fearful places are avoided, attractive places are explored). In other words, humans perceive and respond to their environment. Most geospatial applications however, rely on objective geospatial data to provide services and decision support to its users. This paper reports on results of a research project, which aims at acquiring people's subjective relations to space, as well as at attaining user-centered services by incorporating subjective data into geospatial applications. We will discuss crowdsourcing as an effective approach to gather subjective relations to space, and introduce applications of subjective geospatial data.

Keywords: Subjective Geodata, Crowdsourcing, Routing

1. Introduction

The concept of *cognitive mapping* was first introduced by Edward C. Tolman in 1948. Based on experiments in a maze with rats, Tolman (1948) concluded that not only rats but also humans must be capable of memorizing locations, and of developing an inner picture of the external world, which help guide them in space. Tolman named this mental representation of the external world a *cognitive map*.

Studies on mental representations and navigation show that people use certain key elements (e.g. paths, nodes, landmarks) to organize spatial information (Lynch 1960). However, mental representations of space show various distortions and do not depict realistic images of the external world, but indicate how people believe the world is like (Downs & Stea 1982). According to Lynch (1960, p.6), *"environmental images are the result of a* *two-way process between the observer and his environment. The environment suggests distinctions and relations, and the observer [...] selects, organizes, and endows with meaning what he sees. [...] Thus the image of a given reality may vary significantly between different observers.*"

Physical barriers or semantic unity may affect cognitive maps on the one hand, but on the other hand, biases may also derive from individual interpretations, emotional involvement and attitudes (Carbon & Leder 2005). Such subjective interpretations of space do not only affect a person's cognitive representation of space, but research shows that they affect behavior and decision-making in space (Gallimore et al. 2011, Sullivan et al. 2004, Zacharias 2001, Borst et al. 2008). More specifically, findings of walking route choices suggest that people do not simply decide for time-/distance-optimized routes, but that decisions in space are influenced by various characteristics of the environment (Borst et al. 2009).

Humans perceive, interpret, and respond to their environment. Such evaluations and interpretations are subjective and differ between individuals (Russell 2003, Lynch 1960). In contrast, most geospatial applications rely on objective geospatial data only, to provide services and decision support to its users. However, subjective information about the perception of space may be useful to study spatial behaviour from a user perspective, to better predict people's route choices, and to suit decision support in space in a user-centered way.

This paper reports on results of a research project, which aims at acquiring people's subjective relations to space, as well as at attaining user-centered services by incorporating subjective data into geospatial applications. For this, we will discuss crowdsourcing as an effective approach to gather subjective relations to space, and introduce applications of subjective geospatial data.

2. Acquisition of Subjective Geodata

Subjective geographic information can be collected through various approaches (for a review see Griffin & McQuoid 2012). Traditionally, conventional approaches, such as self reports and psychophysiological measures used to be situated in rather artificial conditions – in laboratories with highly controlled conditions, or have a rather small number of participants equipped with unhandy devices. However, due to recent developments and new technologies, novel methods and approaches for collecting subjective geographic information originate – one of which is crowdsourcing.

For gathering subjective relations to space in this research, we used the crowdsourcing approach to collect data from people using their smartphones to contribute. Due to the ubiquitous use of smartphones and the growth of Web 2.0, smartphones can nowadays be used to capture users' subjective relations to space and contributions can be shared "on the go", and are automatically linked to a person's current geographic location. Volunteers can simply and freely contribute anytime and anywhere, being situated in realistic environments (and not in artificial settings, or equipped with additional devices). With this approach, we expect to collect ecologically valid results, efficiently, and in real-time.

Within this research, the data will be used to for two specific applications:

1) to create a subjective city layer, which will depict people's relations to space
2) for route calculations, which aim to better suit and predict people's behavior in space.

However, the usage of such subjective data is not restricted to the field of navigation only, but can be used for purposes of various disciplines (e.g. planning disciplines, policy makers).

3. Data Applications

Subjective spatial ratings collected in this project, are point-based data, distributed at different parts of the street network. We will illustrate two applications of these data – data analysis and visualization, and routing.

3.1. Data Analysis and Visualization

Subjective geodata gives insights into people's relations towards space. For this, visualization plays a key role. Different techniques can be employed to visualize subjective data, such as dot maps, choropleth maps, cartograms, and interpolated maps. Dot maps are usually used when the data for visualization are point features, representing contributions singularly according to their spatial location. In contrast, choropleth maps use area symbols to depict data. For visualizing subjective spatial data with choropleth maps, data is aggregated to enumeration units, such as administrative boundaries (White 2007). Similarly, cartograms distort or scale the geometry of each enumeration unit to reflect a specific variable (Mislove et al. 2010). In contrast, interpolated maps consider data as continuous phenomena and visualize them as a continuous surface or layer (Jang 2012).

Based on the subjective data of our research, a subjective layer of space was created, depicting people's relation to space on individual and aggregated levels (see *Figure 1*).

Figure 1. Subjective ratings of space depicted individually (dots) and on an aggregated level, from very positive (dark green) to very negative (dark purple) (Klettner et al. 2013).

For interpreting the collected data, the ratings were analyzed according to the contributors' socio-demographic information (e.g. gender, living environment), and context of contribution (e.g. familiarity with space, alone vs. with others). We analyzed to which extent different groups of people in different contexts rate the environment differently, respectively similarly, regarding the subjective parameters comfort, safety, diversity, attractiveness, and relaxation. For this, a study area in Vienna was selected with 473 contributions. Results show no significant differences between ratings of females and males. Similarly, the contributors' living environment had no influence on the ratings. However, people in company showed significantly higher levels of comfort than people who were alone. Also participants familiar with the location being rated, reported the environment to be more attractive and more diverse than people new to a location.

In addition, ratings of different environmental settings were analyzed to study whether different environments are perceived differently. For this purpose, the study area was divided into three urban scenes (urban-green area vs. urban area with light traffic vs. urban area with heavy traffic), and subsequently compared according to the participants reported subjective level of comfort, safety, diversity, attractiveness, and relaxation. In general, urban green areas show the most positive ratings in any of the subjective parameters, followed by areas of urban-light traffic. Urban areas with heavy traffic, on the other hand, show low or negative ratings. For more details on the data analysis, refer to Klettner et al. (2013).

3.2. Enhancing Route Planning in Mobile Pedestrian Navigation Systems

Research suggests that pedestrians favor specific environmental qualities aside from shortness (e.g. Gallimore et al. 2011, Zacharias 2001). Current algorithms often fail to provide other aspects aside from time-optimized and distance-optimized routes. In this research, we addressed this problem by incorporating subjective relations to space. The basic idea is to aggregate (e.g. average) subjective spatial ratings of similar users to model/approximate current user's subjective relations to different street segments in the street network. With this, a street network, in which each segment is encoded with a collective rating, can be generated.

In this research, a top-k shortest path algorithm such as Yen's algorithm (Yen 1971) is employed to find all the paths which are shorter than a threshold between a start and an end. The path with the highest collective emotional ratings is then identified as the "EmoRoute", which considers distance and emotional ratings. The difference between the threshold and the shortest distance can be considered as a detour which users are willing to take for a more comfortable route. Currently, the threshold is set as 110 per cent of the shortest distance. However, this threshold can be also learned from users' travel histories.

A survey was designed to evaluate the routing algorithms and to test the hypothesis that routes based on subjective geodata gathered from users suit people's route choices more adequately than conventional algorithms do. For this purpose, a user study with two video tasks was carried out. The videos showed either a route based on subjective data-points (EmoRoute), or the shortest route according to distance. The two routes had the same starting and end point. To avoid order effects, the video tasks were randomized and participants were randomly assigned to participants of the study. After watching both videos, participants were asked to decide which walk they would prefer to take, and to indicate why.

In total 29 students completed the online survey (*MeanAge* = 25.41, *SD* = 3.99). The results show that, participants preferred to take the EmoRoute over the shortest route (69% vs. 31%). A chi-square goodness-of-fit test showed that EmoRoute were significantly preferred over the shortest one [$\chi^2(1) = 4.172$, $p < 0.05$]. *Figure 2* illustrates these findings.

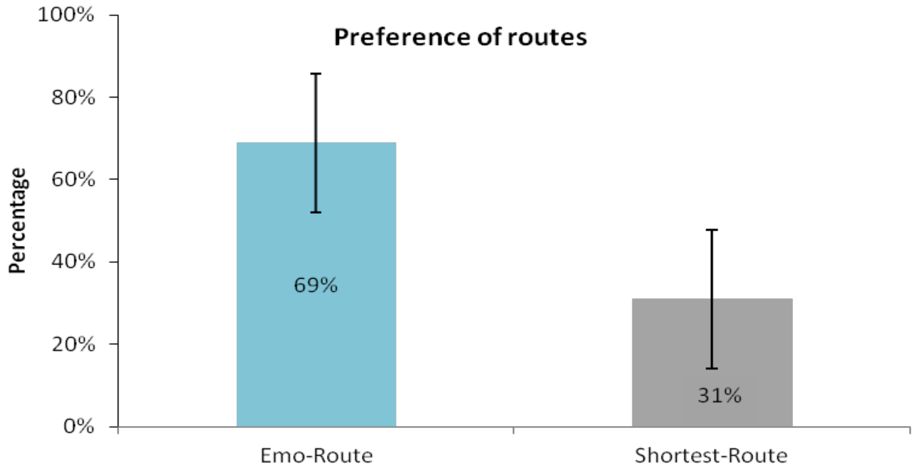

Figure 2. Decisions for the EmoRoute versus the shortest route for the video tasks. Vertical error bars denote 95% confidence intervals.

Findings from literature show that subjective interpretations of space influence spatial behavior in a way that people do not simply decide for time-/distance-optimized routes but take other aspects into consideration (Borst et al. 2009). Results of the evaluation in this study support these findings and show that EmoRoute which is based on subjective geodata gathered from users, suits people's route choices more adequately than the shortest route which is computed based on distance. To sum up, considering people's subjective interpretations of space contributes to the improvement of pedestrian route planning.

It is also important to note that, the current EmoRoute algorithm uses all other people's level-of-comfort ratings to generate collective affective ratings, and provides non-personalized and non-context-aware route planning. For a defined stop and end, all the users will get the same route commendation. To compute more relevant route, techniques like context-aware collaborative filtering (CF) can be used. A vision for this is to filter contributions of people of similar contexts to generate and recommend routes (e.g. "people in similar contexts, similar to you will prefer this route"). CF includes two steps: (1) identifying similar users (this step can be viewed as assigning the current user to a group) and (2) carrying out a popularity-based recommendation for each group of users. Therefore, the proposed algorithm can also be used in the second step of CF.

4. Summary and Outlook

Research indicates that behavior and decisions in space are influenced by environmental characteristics. Results of this research support these findings. In this study, we used a crowdsourcing approach to collect subjective information about space. The results from the data analysis show that different groups of people rate the environment differently as well as that different spatial scenes are perceived and judged differently.

Aside from visualization and data analysis, we deployed subjective geoinformation for evaluating their utility for route services for pedestrians. Results from the evaluation of conventional routing and the EmoRoute algorithm show a closer match of the EmoRoute regarding people's natural route choices. With this, people's behavior can be predicted more adequately and thus, navigation services can more properly be adapted to its users and support users' behavior and decisions in space.

In order to differentiate and tailor such services even more according to different user groups, more data from heterogeneous groups of people must be collected. On the basis of data from diverse user groups, CF will be a promising approach to filter contributions according to similarities. It will be a next step of this research, aiming at even more personalized services for wayfinding.

However, applications of subjective geographic data are not restricted to aspects of visualization and navigation. We expect the inclusion of a subjective layer will bring benefits to different disciplines, not only Information and Communication Technology, but also Urban Planning, Architecture, and Policy Making.

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