Bridging the Social-Technical Gap in Location-Aware Computing

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Abstract

Building ubiquitous applications that exploit location requires integrating underlying infrastructure for linking sensors with high-level representation of the measured space to support human activities. However, the real world constraints limit the efficiency of location technologies. The inherent spatial uncertainty embedded in mobile and location systems constantly challenges the coexistence of digital and physical spaces. Consequently, the technical mechanisms fail to match the highly flexible, nuanced, and contextual human spatial activities. These discrepancies generate a social-technical gap between what should be socially supported and what can be technically achieved. My research aims at exploring, and hopefully reducing this gap in the context of location-aware computing.

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Problem Statement and Research Question

Location-aware systems emerged from the recent evolution of mobile computing, location sensing and wireless networking. They play a central role in ubiquitous computing to sense and react to real-world context. However, physical, technological, organizational or economical constraints limit their use in the real world. Each location and wireless enabling technology carries its own set of limitations and problems in terms of service coverage, stability, connectivity, mobility, cost, privacy and accuracy. Therefore, the advantage of location information can be easily obscured by these difficulties, with an impact on the usability and adoption of ubiquitous systems. Indeed, user of location-aware systems must coordinate their distributed collaborative activities in spite of considerable technical failures, errors and limitations generating uncertainty. As investigated in several field studies on location awareness [5,6,8,13], users struggle with the spatial uncertainty emerging from uneven location sensing and fluctuating wireless networks. These uncertainties are fundamental characteristics of location-based and mobile experiences, and they will remain so for the foreseeable future [6]. While technology providers suggest that there are not limits to connectivity and mobility, service coverage and stability is anything but seamless in the real world.

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These observations reveal a social-technical gap [2] that exposes the need to handle inadequate location information without undermining the benefits of location-aware systems. Indeed, current systems cannot fully support the flexible, nuanced, and contextualized social world uncovered. The social-technical gap is the divide between what we know we must support socially and what we can support technically. My research focuses on bridging this social-technological gap in the context of location-aware computing.

While not standing in opposition to research aimed at improving accuracy and broadening availability of location aware systems, I have been exploring the relation between the granularity of location information a system can deliver in opposition to the granularity users expect. By granularity, I currently define a certain level of information quality and timeliness that locates a person or an object in the physical space. The current stage of my research suggests that the mismatch between the user-expected and the system-delivered location information granularity is a pivotal element of spatial uncertainty. Therefore, a user-centred (rather than hardware-centric) hierarchy of the expected system-delivered location information could help understanding the social-technological gap.

In addition, when spatial uncertainty cannot be technically resolved, designers of location-aware system must apply design strategies to support users activities. This implies finding solutions to manage the discrepancies to the improvement of the user experience. Both, visualization techniques and the exchange of information between the location-aware system and the human user could be applied to reduce the social-technological gap significantly. Therefore, I will attempt to contribute to the knowledge base of supporting strategies for users to manage the experienced spatial uncertainty.

The research question could hence be formulated like this: **How to build collaborative location-aware systems that take into account the spatial uncertainty inherent to ubiquitous technologies?**

This main question covers the following sub-research questions grounded from the literature:

- Highly precise positioning may not always be necessary to support location-awareness. From a field study based on a pervasive game, [11] raise the issue of the degree of positioning accuracy being appropriate to the task or activity at hand. In consequence, **what level of location information quality and timeliness must be delivered in order to be useful and relevant?**
- In their research on the visualization of uncertainty in cartography, [17] note that there is no comprehensive understanding of the parameters that influence successful uncertainty visualization. In addition, they observe that there is a need for a more systematic approach to understand the usability of uncertainty representation methods and interactive interfaces for using those representations. Therefore, in the context of ubiquitous location-aware systems, **what parameters influence successful uncertainty visualization?**
- Based on their work on adaptive automation, [7] argue that the only way of reducing uncertainty is by exchanging information between the automatic system and the human user. In consequence, **what is a balance between implicit and explicit forms of human interaction with a location-aware system that communicates the inherent uncertainty of its location information?**

Approach and Methodology

My research approach matches the growing need in ubiquitous computing research to deploy more real-world experiments to mature the practice of HCI evaluation [1]. Indeed, a good portion of reported work on ubiquitous computing remains in laboratory settings, free from the influences of the real world. In consequence, deeper empirical evaluation results cannot be obtained through controlled studies delimitated by traditional usability laboratory. Rather, the requirement is for real use of a system, deployed in an authentic setting. Therefore, I capture data from a mix of case and field studies to observe (and analyze) the authentic human and collaborative use of location-aware and ubiquitous technologies. My field studies take part of a recent trend in the fields of ubiquitous computing and CSCW (Computer-Supported Collaborative Work), to base research on pervasive gaming to demonstrate principles and lessons that can be applied more generally in systems for mobile work in vast work settings [9].

A first step of my research has been accomplished in using a field study to explore and analyze spatial uncertainty inherent to ubiquitous technologies [13]. Here we dealt both with individual and collaborative aspects. Currently, I am undertaking a case study on the sharing of geotagged information to identify the users behaviors when making use of location information granularity. This gives social perspectives. Another case study aims at analyzing the main issues embedded in the interaction of mobile workers with location information that fails to match a relevant quality. This will provide individually related aspects.

Based on the general lessons of these first three studies [Table 1], I plan a more comprehensive field study to evaluate the design of a city-scale location-aware system. Here, I should be able to analyze the integration of location information granularity in the design of the application, to evaluate strategies to manage spatial uncertainty emerging from the discrepancies between the sensed physical world (i.e. location quality and timeliness) and its virtual representation (i.e. location presentation). Experimental design should enable us to get both qualitative and quantitative data [10].

Table 1: Summary of the studies and their goals

Study	Context	Goal
Field study 1	Collaborative pervasive game played at the scale of a university campus.	Explore the sources of spatial uncertainty and analyze players' behaviors towards spatial uncertainty spatial. Individual and collaborative aspects of spatial uncertainty. [12]
Case study 1	A collaborative platform to share geotagged information.	Identify the users behaviors when making use of location information granularity.
Case study 2	Personal use of a location-aware system (e.g. Taxi drivers using their navigation system).	Identify the main issues embedded in the interaction of mobile workers with location information that fails to match a relevant quality.
Field study 2	Collaborative pervasive game played at the scale of a city.	Analyze the integration of location information granularity in the design of the application, to evaluate strategies to manage spatial uncertainty.

My research questions tend to study the utility of an innovation by means of analyzing current use of location information, and then building and evaluating a location-aware system. I hence rely on a classical design-science research [16] method with an innovation building approach. In consequence, I will execute the similar evaluation methods applied by the main contributors in the domains of ubiquitous computing and human-computer interaction. Following standard and rigorous methods in the evaluation of both the construction and evaluation of my work should allow me to provide clear and verifiable contributions.

Related Work

So far, studies in ubiquitous location-aware computing have strongly focused on optimizing the accuracy of location sensing and tracking information from a technology-driven perspective [14, 15]. In contrast, few user-centered field studies have been performed that would discuss (and perhaps challenge) the need of fine-grained location information to support human spatial activities. In the study on the practical aspects of getting location-enhanced applications deployed in the real world, [4] conclude that we should offer pragmatic solutions for developers delivering real world location systems for widespread use. My work exemplifies this search for a pragmatic approach by defining and evaluating the location information granularity expected by users of location-aware systems.

Similarly, few user-centered studies have been done to understand how to design applications that take into account the lack of maturity, the underlying imperfections and inherent uncertainties of location technologies. In their field study based on a mobile mixed reality game called Can You See Me Now?, Benford et al. [6] highlight the diverse ways in which online players experienced the uncertainties inherent in GPS (Global Positioning System) and 802.11 networks. They suggest that designers should use general strategies to deal with uncertainty: remove it, hide it, manage it, reveal it, and exploit it. They also argue that designers should explicitly consider four potential states of being of a mobile participant: connected and tracked, connected but not tracked, tracked but not connected, and neither connected nor tracked. My work aims at further investigate these strategies by going beyond binary states of trackability and connectivity.

In the same perspective as [6], Chalmers and Galani [8] observe that people accommodate and take advantage of seams and heterogeneity, in and through the process of interaction. In consequence, they advocate that designers of ubiquitous systems may consider selectively revealing differences and limitations of systems, in ways that support social interaction. Similarly, Antifakos et al. [3] base their proposal to display uncertainty on the fact that users are actually used to and highly successful in dealing with uncertain information throughout their daily lives. Their experiments show that human performance in a memory task is increased by explicitly displaying uncertainty information. However, they warn that further studies must be performed on the tradeoff between the increased cognitive load, caused by displaying uncertainty information causes, and the added value that it provides.

In contradiction to these studies arguing that the system usability can be improved by displaying the uncertainty to the user, [18] show that it is not always an advantage to show the confidence of the context-aware application to the user. Based on a user study, the authors prove that the users need slightly more time and produce slightly more errors when the confidence of the system is visualized.

These opposite results consider uncertainty and context as a whole and do not focus on location information and their different sources of uncertainty (e.g. location information quality, timeliness and presentation). Furthermore, these studies do note consider the visualization techniques of spatial uncertainty. In that perspective, based on the review of the methods to visualize geospatial information uncertainty, [17] note that there is still no comprehensive understanding of the parameters that influence successful uncertainty visualization. Finally, these investigations do not explore the exchange of information between a location-aware system and its user as an approach to reduce uncertainty.

Preliminary Results

I started this research with a main observation that the quality of the location information impacts the usability of location-aware systems. In a preliminary field study based on a pervasive game [12] I was first able to define a taxonomy with three layers of sources of spatial uncertainty:

- The location quality predicted through sensor measurements and observations. Uncertainty is generated by patchy location service, fluctuating signal strength, deviations in positioning, devices limited resources, but also from processing the measured data themselves.
- The location timeliness indicated by the time that has elapsed since the location was acquired. The temporal accuracy of a location is influenced by the network connectivity, communication latency and location update mechanism.
- Location presentation, i.e., the ways which deliver location information to the user. Geometric, symbolic and map representation can be misleading or ambiguous

Second, based on qualitative data collected from both field observations and post-experiment questionnaires, I could define categories of user behaviors towards spatial uncertainty. In the analysis, from the systematic coding of the specific users reactions and their description, I categorized the reactions of users confronted to a discrepancy into: believing, overcoming and not understanding the system. The preliminary results [12] presented at the UbiComp 2006 conference poster session show that, when confronted to spatial uncertainty, humans react differently depending on the location information they receive, the source of uncertainty, implicit information (e.g. familiar with the environment, knowing the partner), and the activity (e.g. searching, coordinating, planning).

Finally, I remarked the lack of user-centered perspectives on the granularity of location information in the ubiquitous computing literature. However, an inspiration might come from the concept of generalization applied in the field of cartography. Cartographic generalization is the process of selecting and representing information adapted to a scale to make the map useful.

Conclusions and Future Steps

My research is inspired by William Buxton's aphorism "Let's do smart things with stupid technology today, rather than wait and do stupid things with smart technology tomorrow"[2]. Indeed, the recent emergence of location-aware computing enables us to benefit from systems that sense and react to a physical context. Yet, the limitations and constraints related to the underlying technologies create a technical-social gap in the use of such systems. Therefore, to reduce this gap,

[2] in a talk at the IFIP WG8.4 Conference, Crete, September 1990

I suggest gaining a comprehensive understanding of the human individual and collective use of location information. Similarly, there is a need for a more systematic approach to understand the usability of uncertainty representation methods and interaction supporting the use of those representations.

The next steps in my research are based on the investigation of the current use of location information granularity and of the interaction with uncertain spatial information through two case studies. I cooperate with organizations and researcher groups owning great amounts of user-generated location information to use for my case studies.

In addition, I will build a city-scale system to evaluate design strategies to manage spatial uncertainty in order to match a user-expected granularity in the location information. Beyond examining the usability (Does it work for the user?), and the contextual impact on usability (Where does it work?) I aim at exploring and comparing various design strategies impact on usability (When and compared to what does it work?) and, as a result, derive guidelines that can be applied to other designs.

Since I have already performed an observatory study and an extended literature review of my research interest, I am aiming at gaining insights and recommendation on the approaches to apply in my experimental designs. With my engineering background and mixed research domain, I thrive on collaboration with social scientists.

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