Towards Reducing the Social-Technical Gap in Location-Aware Computing

by

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Abstract

Along in their history, humans never ceased to create techniques and tools for observing their environment and locate themselves in the physical environment. This attests our necessity to be aware of who and what is where and when – a concept that we term location awareness. Nowadays, the democratization of mobile and wireless technologies increases people's awareness of their whereabouts. However, it also their interaction with the physical environment and by consequence impacts the social interactions and work practices.

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. This thesis contributes to the research in the field of Computer Supported Cooperative Work (CSCW) and ubiquitous computing by exploring, and hopefully reducing this gap in the context of location-aware systems.

Our preliminary work reports on complementary studies of some of the aspects of the social-technical gap. This preliminary and current work, takes very different perspectives on the use of location-aware applications. These views highlight the role of the spatial context and technological limitations in the use of the systems features. First, we explored the impact of the technical limitations in collaborative tasks experienced in the form of a location-aware game. It allowed us to define the sources of spatial uncertainty perceived by the users while interacting with the system. Then, we investigated the social requirements of linking information to space. In particular, we report on the influence of space in the use of location granularity to share and retrieve photos. Finally, we describe an ongoing ethnographic study of the evolution of taxi drivers practices with the introduction of location-aware and navigation systems in their work. This work reveals the ways positioning technologies influence the work practice of mobile workers. For instance, some drivers access the geospatial information as in a "funnel". They start a ride with a general idea of an area surrounding the destination. As they enter the targeted area they access detailed information for the specific destination with location-aware application.

The extensive review of the domains of ubiquitous computing and CSCW shows that more of the research in those fields focus on optimizing the accuracy of location sensing and providing seamless interaction. On the other hand, limited work has been pursued to understand the social-technical issued in real-word settings and provide solutions to match the visions of supporting people's everyday life activities. In consequence, we suggest research perspectives that should contribute to this agenda. Through real-world field studies, we aim at providing solutions for the design of collaborative location-aware systems that take into account the spatial uncertainty inherent to ubiquitous technologies.

Keywords: location-aware computing, spatial uncertainty, CSCW, location-awareness.

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Chapter 1
Introduction

There will come an age in the far-off years
When Ocean shall unloose the bonds of things
When the whole broad earth shall be revealed
Seneca

Humans rely on their perception of the nature and the environment to link their physical presence to a representation of their surrounding space. Knowing about where we are and what is around us is so important that early in the human history and prior to any other written form of communication, the activity to graphically translate observations into maps appeared. In their quest of exploring unknown worlds, early navigators instigated and benefited from the invention of the astrolabe, magnetic compass and sextant. These tools enabled increasing accuracy in locating and predicting positions. Nowadays, we continue adapting the resources and technologies available in our environment to perceive the physical world. The democratization of the mobile wireless systems allows now the exchange of the position of people and objects in a mobile context. This impacts the social interactions and modifies work practices. For instance, people prefer to know who else is present in a shared space, and they use this awareness to guide their work (Erickson et al., 1999). The historical co-evolution of human needs to perceive their whereabouts using maps and positioning techniques attests our necessity to **be aware of who and what is where and when** – a concept that we term **location awareness** in this thesis.

The increasing power of mobile devices, coupled with the spread and quality of positioning technologies, means a modification of people's interaction with their social and physical environment. This emergence of connected mobility freed ourselves from some spatial constraints. In consequence it increased the importance of spatial context in our communication. For instance, "where are you?" has become the recurring question opening conversations over mobile phones. In fact, the importance of space and place has been made more relevant with the ubiquitous computing paradigm, which aims at the integration of computation in physical objects places (Weiser, 1993). Among other technologies in this domain, there is a surge of location-based services, which is to say mobile applications that take advantage of location information in various contexts like supporting group coordination, playing game or engaging users in learning activities (see Benford, 2005 for a review). These services enhance human activity by providing awareness on people and objects positions in the spatial environment. They rely on sensors to link aspects of the physical space to a digital representation. In order to render meaningful and relevant information the overall context of use must be taken into consideration. However, providing expected location information from measurements of the physical space poses at least two issues.

First, due to physical, technological, economical, social or political constraints, location-sensing systems deliver imperfect measurements of the physical space. Each system carries its on set of limitations in terms of spatial accuracy and coverage. Moreover, as being used on the move, these technologies suffer from external elements that create a fluctuating quality of service. For example, Global Positioning System (GPS) sensors prove to be more accurate in the open with a clear line of sight to the sky and less accurate when behind the shadow of buildings. This difference is not insignificant and accuracy can vary from a few meters to tens of meters. In addition, location information is only available for the past when there is a delay between the location sighting and the delivery of the information. This temporal accuracy sometimes caused by unstable network conditions can impact the relevance of the information and defy the purpose of a location-aware application.

Second, human activity is highly flexible, nuanced and this makes systems technically difficult to construct properly and often awkward to use. The context guiding the use of location-aware systems is constructed in and through the dynamic of each individual's social interaction. This complex and nuanced situated construct makes it challenging to formalize and objectify into a computerized model (Chalmers 2004). Therefore, it makes hard to build systems that technically support the desired social requirements

The discrepancies between the technical mechanism and social requirements of location aware computing create a **social-technical gap.** As depicted in Figure 1, this gap lies in the heart of the research in Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW). Ackerman (2000) describes it at the *divide between what we know we must support socially and what we can support technically*. In other words, the complexity and embedness in our daily activities make understanding it and reducing it hard to do. As consequence, we do not really know how to build systems that fully support the social world (Barkhuus, 2004). This gap is particularly wide in location-aware computing because in one hand the underlying technologies suffer from many limitations and on the other hand the social requirements depend on dynamic mobile contexts and privacy issues. The signs of the gaps in the use of location-aware application can take the form of experience of uncertainty in the information, ambiguity in the interaction, confusion on the intention, or frustration due to time lost. These shortcomings pose new design challenges that are hard to solve in location-aware computing. Some of the idealization of the perfect system must be ignored to provide a working solution; this trade-off provides much of the tension in any given implementation between "technically working" and "organizationally workable" systems (Ackerman, 2000). In fact, interface designers will increasingly have to wrestle with this tension to match physical form to the capabilities of sensors and the shifting requirements of applications (Benford et al., 2005).

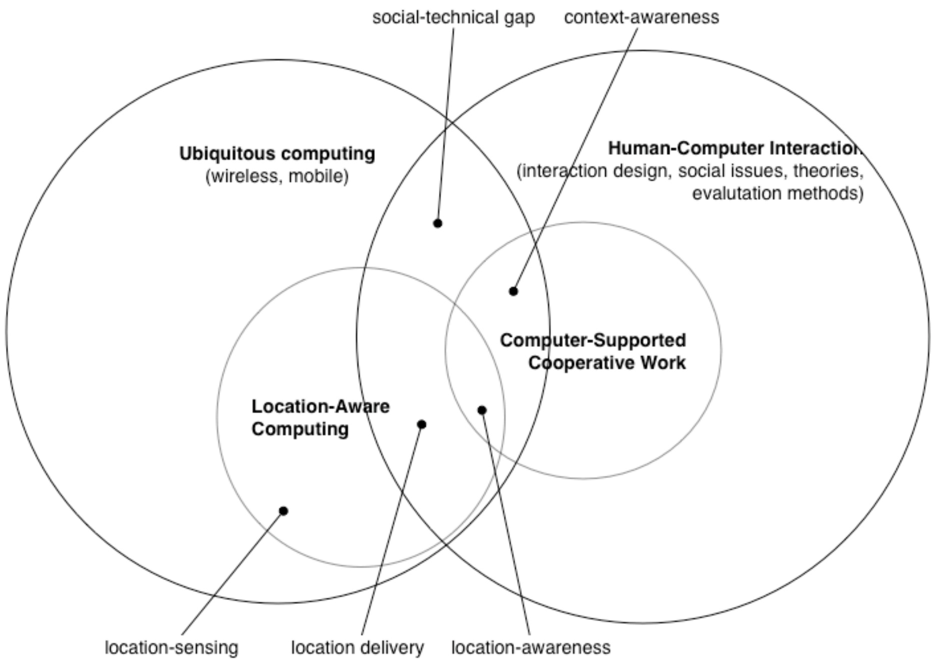


Fig. 1. The social-technical gap is the fundamental problem of CSCW (of generalizability from small groups) and (HCI prediction of affordances) and the application of new technological possibilities such as ubiquitous and location-aware computing.

While we do not go against striving for seamless, continuous connection and for perfect positioning algorithms, there is a need for alternative ways of linking the physical space to its digital representation. We propose to take into account the limitations location technologies in relation to the social requirements of location-awareness. For example, location information is not only about accuracy, but also mostly about and providing appropriate information. Therefore, it is relevant to ask ourselves how good is good enough to support location-awareness. The integration of the infrastructure imperfection in the design of application supporting group interaction could help match the expectations and visions behind ubiquitous computing.

This thesis presents the preliminary and current exploratory work this social-technical gap in the domain of location-aware computing. Our research so far has investigated some instances of the issue such as the technical limitations, the contextual factors influencing the use of a location-aware system, and the people perception of spatial uncertainty and the different levels of location information granularity. Based on this early work and an extensive literature review we propose research perspectives we believe to be valuable to understand and help reducing the gap. We structured this thesis in three main chapters.

Chapter 2 reports on the first and early results in understanding the social-technical gap in location-aware computing. We used three different studies, to explore several aspect of the gap. First, we conducted a field experiment in the form of a location-aware game that reveled the sources and reactions to spatial uncertainty. Then, we comment the first results of an observational study of the factors influencing the use of location granularity to share and retrieve photos. Finally, we describe an ongoing ethnographic study of the evolution of taxi drivers practices with the introduction of location-aware and navigation systems in their work. We are particularly eager to determine the role of the spatial context and technological limitations in the use of the systems features. Finally, we present spatio-temporal data analysis tools developed to support our observations of people's use of location-aware information.

Chapter 3 provides the theoretical background from a literature review of the research domain. We set the general visions and challenges of the integration into our daily lives of ubiquitous technologies. This third wave of computing (Weiser, 1993) with its connected mobility and context-aware mechanism challenges scholars to modify the methods to evaluate people's interaction with computer systems. Moreover, the increased complexity of context of use and wideness the social-technical gap. In consequence, we draw the implications on the narrower domain of location-aware computing and the design of location-aware applications to support social processes.

Chapter 4 concludes in planning complementary research perspectives that aim at reducing the social-technical gap in location-aware computing. We restate the issues future research would need to investigate by answering specific questions related to the design of location-aware system with consideration of technological limitations and social requirements. To be able to answer the questions, we propose methodology and approach we believe appropriate evaluate the results of the research process.

Chapter 2
First and current results

We started this work 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 (Girardin et al., 2006) we characterized the sources of uncertainty inherent to the emerging ubiquitous technologies. Additionally, based on qualitative data collected from both field observations and post-experiment questionnaires, we could define categories of user behaviors towards spatial uncertainty. With the systematic coding of the specific users reactions and their description, we separated the reactions of users confronted to a discrepancy into: believing, overcoming and not understanding the system. This preliminary results 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, the development and deployment of a pervasive application confronted us with the technological constraints in out of the lab, real-world settings.

This preliminary work led us to consider the social-technical issues influencing the experience of location-aware systems. We remarked that spatial uncertainty was not always perceived as negative and sometimes was even ignored. Since humans seems to handle imprecision, ambiguity and imperfection to a certain point, “how good is good enough?” or “what quality in the location information do people need to support them in their activity?”. So far, the domain of ubiquitous location-aware computing has mainly been investigating the improvement in accuracy, precision and coverage. In contrast, we take a perspective centered on the human activities to observe where the limit of the “good enough” stands and what are the influencing factors on the need for accuracy to convey location information. We report on an observational study of people sharing and retrieving location-enhances information at a different level of granularity. This works takes the context of the widely popular photo-sharing platform Flickr[1]. Our first results show the influence of the urban environment on the accuracy linked to a photo.

The domain of location-aware computing also often employs lab-based controlled environments to study the usability of the systems. The results of these works contrast with our experience and observations of users of real-world uncontrolled settings. Moreover, their limited time periods fail to take into the consideration the co-evolution over time of the technology and its user. In other words, “how do people appropriate the control of a location-aware system?”, “how do they adapt to the imperfection of the system over time” and “when and where is a system actively, passively or not used?”. To approach these questions, we are currently conducting a pilot ethnographic study with taxi drivers of Barcelona, a massive community of early adopters of location-aware system. Our first results show that there are strong contextual factors that influence the use of a location-aware system

[1] http://www.flickr.com

in a large urban environment. They influence the dynamic of access to the information needed to reach and leave a destination.

The reminder of this chapter describes each of the research works and their current outcomes (summarized in Table 1 and reported in Girardin, 2007). Finally, we take some time in presenting the spatio-temporal data analysis tools that we developed to support our analysis of people' mobility.

Table 1. Concepts, methods, objectives and results of the first and current research work

Concept	**Method**	**Objective**	**Current results**
Spatial uncertainty in location-aware application (Girardin et al., 2006)	Field experiment (mixed qualitative/quantitative), based on a pervasive game.	Define aspects of uncertainty in a collaborative activity supported by a location-awareness tool.	Taxonomy of sources of spatial uncertainty. Categorization of the reaction to spatial uncertainty Reported experience in the design and deployment issues of a pervasive location-aware system
Use of granularity in location information sharing and retrieval (Girardin and Blat, 2007)	Observatory study of a popular photo sharing/storage web platform (quantitative)	Define the factors that influence the use of different levels of accuracy to attach a location to an information. Reveal the evolution in the use of the accuracy feature.	Different urban settings (cities) lead to two different type of use of accuracy Familiarity with the environment does not influence the use of accuracy
Contextual use and user co-evolution with location-aware system	Ethnographic, contextual inquiry of taxi drivers in Barcelona (qualitative)	Describe the contextual factors that influence the active, passive and no use of a location-aware system (GPS navigation system). Report on the co-evolution with the technology.	When driving the specific unknown destination some taxi driver use a "funnel" to access the geospatial information. They start the ride with coarse-grained information and refine it as they get closer to the target. A location-system comes handy to get back on tracks when there are not other contextual cues.

2.1 Spatial uncertainty in location-aware systems

The investigation in ubiquitous location-aware computing still has not reached the promises of seamless technological integration in our daily life. Partially because most mobile, distributed systems and sensor technologies have their faults and limitations, even if users of ubiquitous technologies often learn to avoid, rectify or adapt to the systems failures. However, there is still a lack of information concerning how they impact the experience of location-aware systems in a collaborative setting. Therefore, we proposed to use a 'field experiment' approach based on a pervasive game platform (Girardin and Nova, 2006). Our aim was to rely on a mix of qualitative and quantitative evaluations define aspects of uncertainty in a collaborative activity supported by a location-awareness tool. This section describes the platform we used for the investigation. Then we highlight the three major outcomes of the study: a taxonomy of sources of spatial uncertainty, a categorization of the players' reactions to spatial uncertainty, and the reported issues in developing and deploying a ubiquitous location-aware system in a real-world environment.

2.1.1 CatchBob!

Our approach uses a pervasive game called CatchBob! as an experimental platform for running psychological experiments (Nova et al., 2006). We designed and developed Catchbob! to elicit collaborative behavior of people working together on a mobile activity. In the game, groups of three teammates have to find a virtual object on a university campus. Completing the game requires the players to surround the object with a triangle formed by each participant's position in the real space. To reach this goal, they employ an application running on Tablet PCs as depicted on Figure 2.

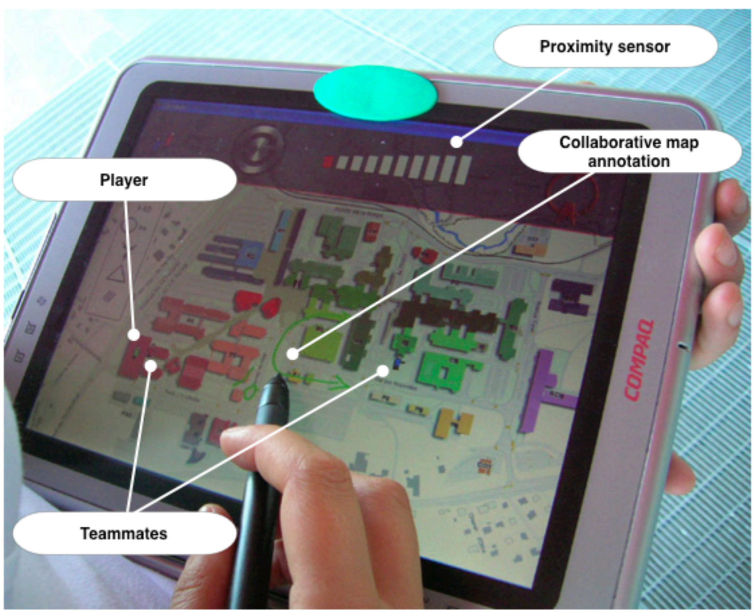
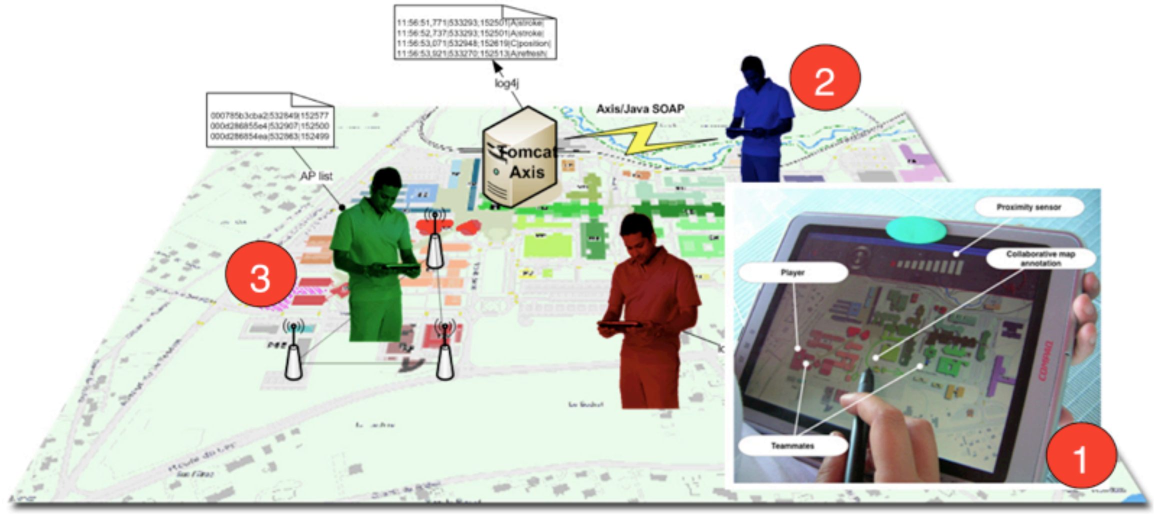


Fig. 2. The CatchBob! interface: Avatars represent the position of the player and his or her teammates. A stylus is used to communicate by annotating the map. A proximity sensor shows the relative distance to the object "Bob" to catch.

The mixed indoors and outdoors settings of CatchBob! prevented us from employing GPS (Global Positioning System) to position the players. Indeed, the campus buildings, corridors and hallways were not offering sufficient line of sight to the sky to acquire reasonable signals to compute a position. In consequence, we chose to apply another positioning technique based on radio beacons. It proved to be the only viable solution for the scale of our game as we could take advantage of the approximately 300 WiFi access points deployed on the campus. Our radio-based (WiFi) positioning relied on an empirical model, which is based on storing pre-recorded measurements in a database. In this solution, an algorithm computes the position based on the position of the access points and the signal strength of a radio wave received by the Tablet PCs. The mobile clients self-determine their position by dialoguing with the Place Lab[2] native libraries to retrieve the MAC address and the signal strength of nearby WiFi Access Points. A basic centroid algorithm matches these data with a list of the WiFi access point's MAC address and the label of the room where it is located and its x and y position (in Swiss coordinates). This approach performs a fluctuating positioning accuracy of 10-50 meters depending on the number of nearby WiFi access points and other external factors such as the architectural setting.

In addition, each Tablet PC enable communication as players can synchronously annotate the map with the stylus. The annotations constantly fade out until they become completely invisible (after 4 minutes). Another meaningful piece of information given by the software is an individual proximity sensor that indicates whether the user is close or far from the object through the number of red bars displayed at the top of the interface. All the players' interactions with the applications (positions, annotations, getting others' positions, connection loss) were logged. We also developed a replay tool that allows showing the paths of each player. This application allows us to confront the players to a replay of the path they took during the game, as well as the actions they performed. A lot of information can be gathered from this to make sense of what happen during the game. The original game took place on the Swiss Federal Institute of Technology Lausanne campus, whose dimensions are 850x510 meters field mixing both indoors and outdoors (see Figure 3). 50 games were played over a period of several months and in several weather conditions. They led us to three different outcomes described in the following sections.

[2] http://www.placelab.org



The CatchBob! architecture: (1) Players use TabletPCs to view their and the other players' position. They communicate by annotating the map with a stylus. (2) The data are synchronized over the campus 802.11 network using the SOAP protocol. (3) The positioning algorithm runs on each mobile device. It computes the player's location based on the position of the access points and the signal strength of a radio wave received by the Tablet PCs.

Fig. 3. The CatchBob! architecture

2.1.2 Sources of spatial uncertainty

Our experience in designing, deploying and analyzing the game allowed us to characterize a taxonomy of the types of spatial information and their main sources of spatial uncertainty (Girardin et al., 2006). We classified them according to the reactions of players confronted to the imperfect location information conveyed by the location-awareness tool:

- 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.

2.1.3 Reactions to uncertain spatial information

Taking into account the source of spatial uncertainty and the type of location information, we additionally categorized the reactions of users confronted to a discrepancy into: believing, overcoming and not understanding the system. Next, we illustrate this classification with typical examples. Players mentioned cases of not understanding the system when both place-based and people-based location information were greatly delayed (location timeliness). One user indicated, "*I stopped for a long time as I was not receiving any messages and the proximity sensor was not moving. I started wondering whether the system was working*".

While disturbing, location timeliness was often overcome in moments of lost location awareness of one teammate. For example: "*It is quite disturbing. I was telling myself that Verena was in the CS building, we could see her there, but I was thinking that she was not there anymore because she had been static for too long*".

Jitters in the absolute and relative positions were perceived as disturbances that only slightly modified the experience as expressed by "*I did not move physically, but I moved on the map. The proximity to Bob changed even though I did not move*". However, we found very severe reactions such as this player who "*stopped with 8 bars in the proximity sensor, then stepped back a bit and received 4 bars. I was not sure anymore if the proximity sensor was according to Bob or the other players*".

Facing a potential discrepancy, participants reacted using the other contextual information available from other coordination devices they had such as knowledge about the environment, experience with the network or precedent experience with their teammates.

2.1.4 Issues from the real-world

Many pervasive systems assume an even quality of sensor data and reliable infrastructure. From our experiences of deploying and maintaining CatchBob! we've found neither is true. We have been able to identify a set of recurrent issues described in the following subsections (Girardin et al. 2007).

Wireless networks are neither open nor pervasive, nor stable: The WiFi network topologies on both campuses were not planned for a pervasive mobile experience, but rather for a nomadic use of mobile device. Indeed, the coverage is limited to places where people work, study or gather. In contrary, alleys, big corridors and parks outdoors frequently proved to be cold spots.

The balance between positioning accuracy and network connectivity: The mixed indoor and outdoor settings of the campus in Lausanne prevented us from employing GPS (Global Positioning System) to position the players. Indeed, the campus buildings, corridors and hallways do not offer a sufficient line of sight to the sky to acquire reasonable signals to compute a position. We therefore chose to use another positioning technique based on radio beacons. In this solution, an algorithm computes the position based on the position of the access points and the signal strength of a radio wave received by the Tablet PCs. This approach performs a positioning accuracy of 10-50 meters, which consistently decreases when the user is in areas of low network connectivity.

Infrastructures are inherently messy: Early in the design process we were surprised that rain, humans, and leaves on trees strongly affect WiFi and GPS performance. The weather had a significant impact on game sessions. For instance we had to cancel several games to keep the rain and humidity from damaging our mobile devices. The outdoor setting forced us to improve the high contrast of colors on the screen for better use in sunny days and add audible queues for message and annotation delivery for the noisier outdoor environment. Likewise, network infrastructures are living creatures regularly mutating into new standards and topologies. In consequence, the positioning system had to be maintained with the constant update of the position of the radio beacons.

The uniqueness of devices: While running the experiments, we became aware of the strong “uniqueness of devices” that we were only vaguely aware of ourselves. Similar types of TabletPC, with similar hardware and software, in a similar context had different network or stylus sensitivity. Players became aware—and angry about—the fact that his WiFi antenna had a significantly lower sensitivity than his team–mates’, even though they were using the same device as was found in a similar work

2.2 The granularity of location information

Our first study revealed the difficulty of location-based application in conveying a meaningful representation of whereabouts. However, still very little work has been dedicated to understand how accurate is accurate enough. In other words, what is expected, sensed and desired from location technologies. In consequence, we setup an other study that aims at revealing new evidences to understand how we link digital information with physical space (Girardin and Blat, 2007). In our approach, we take advantage of the recent burst in the use of capture devices (e.g. mobile phones, digital cameras) and collaborative web platforms to share their content. This new type of user-generated information provide large amount of data to study how people make sense of location accuracy when explicitly binding digital data to the physical world.

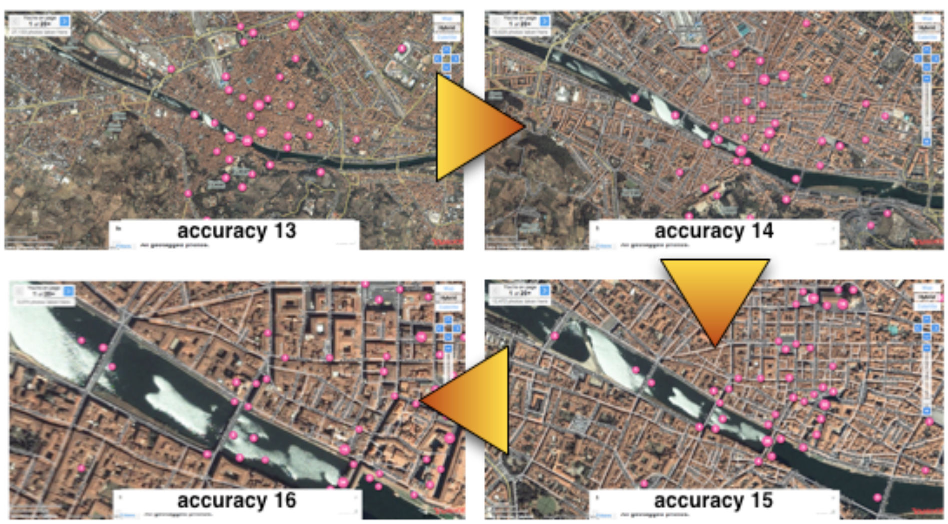


Fig. 4. Accuracy levels defined in Flickr to geotag photos. The image show the transition from level 13 to 16 for the city of Florence

We study the photos uploaded on to the popular photo-sharing platform Flickr. People use this service to share and organize photos with the option to geotag (i.e. link to a physical location) them. Users mainly perform manual geotagging through a map interface. Each time a photo is linked to a position, the system assigns an accuracy attribute according to the zoom level of the map used to disclose the location of the photo (e.g. from 8 for region/city level to the most precise 16 for street level)(Figure 4). The collected data allow us to study two aspects that might influence the granularity employed to anchor images to the physical space (Table 2).

Table 2. Our studies aim at revealing the factors that influence the use of the accuracy feature in Flickr. We start with 2 possible relations that can be observed with our data.

Influence in granularity	**Aim**	**Method**
Type of urban environment	Does the type of urban landscape influence the granularity used?	Map the disclosed location information and accuracy level linked to photos to reveal which areas favor the use of the different accuracy
Familiarity with the area	Does attaching a position to a photo taken in a familiar area influence the granularity used?	Categorize users in inhabitants and visitors of Barcelona. Observe how each group use accuracy over time and space

2.2.1 Early results

Our early results confirm the potential of our approach to understand how people employ the accuracy of location information to link digital information with the physical world. We believe that it can provide further understanding on the nuances in the granularity employed by people to retrieve and communicate location-enhanced information. As a result, it could provide informed suggestions and guidelines for the design of future location-aware applications to match what can be sensed by technologies with what is expected by users.

The comparison of twelve of the most geotagged cities in the world revealed **two major patterns in the way users employed the accuracy feature**. In a first group of cities the use of accuracy peaks the large city and street level, leaving levels in-between underused. On the other hand, another group of urban environments reveal a steady growth in the number of photos from coarse to fine grained granularity without any specific peak at the large city level. As a result, understanding the influential factors to the use of city level type of granularity in some cities and not others needs a deeper investigation.

Further, the unique analysis of the city of Barcelona reveal that the vast majority of photos are bounded to the tourist heart of the city. **Photos with coarse-grained location information (i.e. accuracy 12, city level) are linked with the major and easily detectable points of interest of the city**. The neighborhood accuracy almost uniquely targets the dense urban space of the old town and seems irrelevant to disclose photos taken in the main points of interests. On the other hand, fine-grained location information (i.e. street level) emerge in the main path taken by tourists, but are barley present in the wide space such as the city parks (Figure 5).

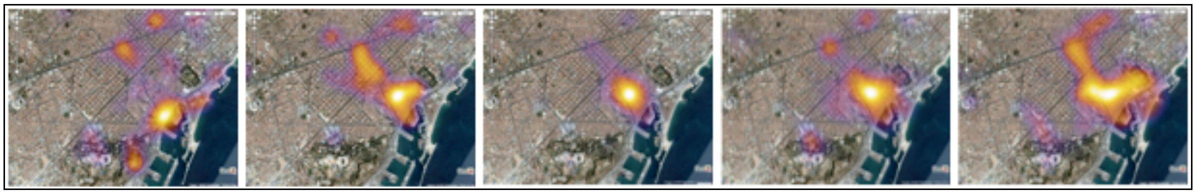


Fig. 5. Heat maps of Barcelona revealing the density of the photos for the accuracy levels 12 (first from left) to 16 (last from the left).

2.2.2 Next steps

The next steps in this study aim first at conducting a more systematic analysis of the collected data to define the influence of space on accuracy. Second, we plan to investigate the link between the intentions for geottaging (e.g. retrieving, communicating) with the accuracy. Finally, the data should help use understand in more details the profiles of "geotaggers" and the evolution in the use of the accuracy feature. In consequence, we are developing a spatio-temporal data analysis tool to investigate the use of the spatial features in Flickr and expand the study over the selected cities.

2.3 Contextual use of location-aware applications

In a third study we are interested in observing where and when do people use location-aware systems and how they deal with uncertain information. We take the approach of using ethnography, often used in ubiquitous computing to evaluate how the applications are experience in situ (Dourish, 2006; Crabtree, 2003). It is a useful means of understanding the adaptations that are required to make new technologies "fit" complex arrangements of real worlds, real time activity (Tolmie et al., 2002). This should inform the design of future applications on the importance of uncertainty and granularity.

The study takes place in the taxi driver community in Barcelona, as they represent a massive population of early adopter of location-aware navigation systems. Moreover, they have a strong past practice of relying on mobile technologies and maps to support their work. This represents an opportunity to gather information and observations from the co-evolution of people with location-aware systems in urban settings. We plan to know more about how the technology influenced the practice and how the practice influences the customization of the tool. In consequence, we currently study the dynamic in the choice of mode of the system (e.g. when and where is it use actively, passively or not at all) and the contextual settings that influence the choice.

Other scholars have focused on the use of navigation systems, but they mainly relied on quantitative data collected from surveys (Svahn, 2004). We aim at augmenting this knowledge from a qualitative, in situ perspective. Other scholars have focused on mobility supported by technologies to access information (Perry et al., 2001) or visit a place (Brown and Chalmers, 2003), rather than being part of the activity (i.e. go from one point to another).

2.3.1 Targeted inquiry

This ongoing study explores the following questions:

- When is the system used? That is at when does the driver need it during a service (e.g. start, to complete the task, at a special event such as finding points of interests or hotels).
- Where is the system used?: in dense urban area, countryside, main roads, familiar zones, unknown remote areas. What type of mode (active, passive, turned off) is used and when (the contextual factors the influence the choice and the dynamic of choice).
- What kind of geoinformations are used by the drivers both from the system and from the environment (experience, radio, interaction with customer, context such as visibility to landmarks).
- What determines the use of a location-aware systems over other systems? (mobile phone, maps, index of the streets)
- How does the co-evolution process unfold? Collect anecdotes on the evolution of the driver's relation with the system. From the acquisition and setup to the point of clearly defining what the system can and cannot deliver. For instance, how the drivers learned the limitations of the system. How much the system can be trusted and what is the reaction when the quality is not met (awareness of the limitations/imperfections)

2.3.2 Data collection and analysis

We plan to perform a first run of 20 contextual inquiries at the taxi resting zone (Figure 6a) at the Barcelona Airport. It takes three parts:

1. A survey (ratio, ordinal and nominal scale) with 21 variable including the age, gender, educational level, but as well groups of variable on the familiarity with the work, familiarity with the area, experience with the navigation system, context of work (e.g. use of other artifacts or tools to support location-awareness)
2. Let the taxi drivers annotate a map of the area to know where and when they use the active or passive mode of the system, what are the areas raising spatial uncertainty issues.
3. Focused ethnography in a 30 minutes ride from the airport to a non-obvious place in the Barcelona city center (Figure 6b).

Fig. 6. (a) The taxi resting area, the stage of the first part for the study. (a) Focused ethnography in a taxi.

The coding aims at categorizing the unitary tasks (e.g. navigation, search destination, self-location awareness) of the taxi drivers and understanding what type of mode and geospatial information is applied for each. This coding should trigger anecdotes on the limitations/uncertainty experience (if there are any), what was the evolution process as of defining the limits of the systems.

2.3.3 Early results of the pilot

So far, we have only run 6 contextual inquiries of 30 minutes between the Barcelona city center and the airport. The results are rather promising, as taxi drivers have no problems in providing anecdotes on a technology that changed the work practices of many. A couple of trends emerged on the contextual use of their location-aware systems:

Reaching the specific destination. During the ride to a rather unknown destination, he accesses the geospatial information as in a “funnel”. First, he checks in the paper-based guide of the city to know more or less the area he should direct to. In that area, he waits for a traffic light to type the exact address in the navigation system. He explained that he engages with the system at that moment to avoid the often-misleading information on the path to take. Indeed, a taxi driver applies several paths depending on the time of the day and circumstances (e.g. traffic, weather conditions, recommendation of passenger). In fact, this specific taxi driver could name me the places where he experienced the navigation information to be absolutely irrelevant (e.g. get access to the forum area, plaza de Glories).

Getting back on track. A main problem for a taxi driver is to be lost after dropping off a customer. This often happens when the customers guide to the destination. Therefore, taxi drivers thrive on information to get back into known territory. That can be landmarks (e.g. a tall building), the topology (e.g. a mountain/hill). But getting a sense of orientation can easily become problematic (e.g. during nighttime or bad weather conditions when tall buildings and mountains are not clearly visible). This is where the GPS comes handy. This specific taxi driver would ask them to give him the way out by typing “Plaza Espana” (i.e. a large roundabout in the center of Barcelona).

2.4 Spatio-temporal data analysis tools

This section reports on work at the crossroads of information visualization, “interaction analysis” and urban analysis. We use the term interaction analysis in a broad sense, meaning that we also on people’s actions in the environment (e.g. movement in space). Interaction analysis focuses on how to aggregate, sort and analyze interaction data (qualitative or quantitative) in order to present them as high-levels indicators, often in the form of visual representations (Dimitracopoulou et al., 2005). It is potentially of interest for three kinds of people: researchers, designers and urban analysts. Like other scholars (Ratti et al., 2006) we develop these tools to investigate spatial behavior over time in order to reveal hidden patterns, but also to thicken the contextual observations (Crabree et al., 2006)

2.4.1 CatchBob! Replay Tool

In Catchbob! we developed a replay tool (Figure 7) to display the position of each group member along the course of the game (Nova, 2007). It used the data from the logs created during each game. The traces of the activity were presented to help players in giving an account of what happened, an interview technique know as self-confrontation (Theureau, 1992).

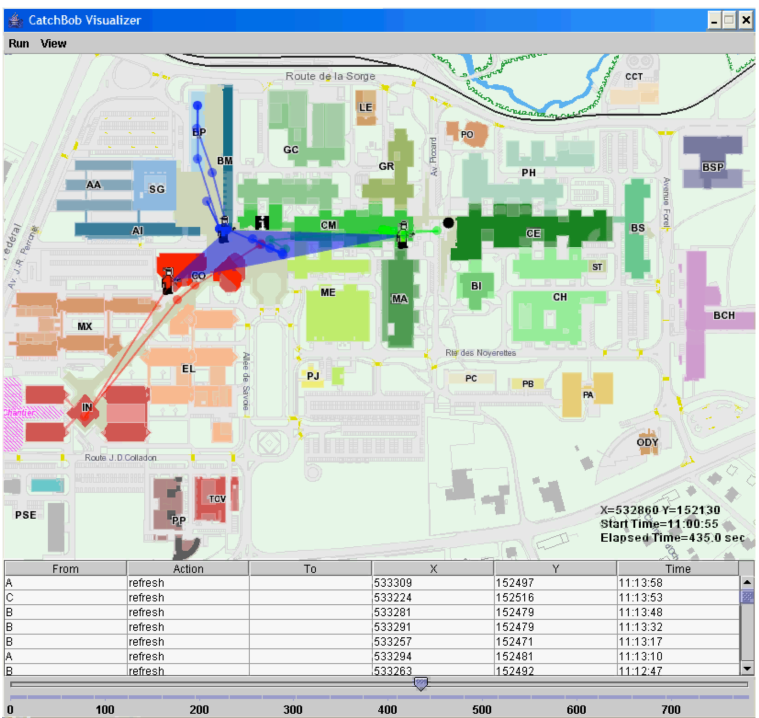


Fig. 7. CatchbBob! Replay tool

2.4.2 Digital footprints geovisualizations

As exemplified by our study of Flickr, in the recent years, the large deployment of mobile devices led to a massive increase in the volume of records of where people have been and when they were there.

The analysis of the accumulated archives of such spatio-temporal data can derive high-level human behavior information valuable to urban planers, traffic engineers, and tourism authorities. In our study of Flick we analyzed the history of physical presence of people from the digital footprints they publicly make available on the world-wide web. Based on the time, explicit location and people's description of their photos, we design geovisualizations (Figure 8) to reveal the activity and flows in space and time. In addition, they provide clues on the influence of the type of environment and the familiarity with the environment on the location accuracy used to link a photo.

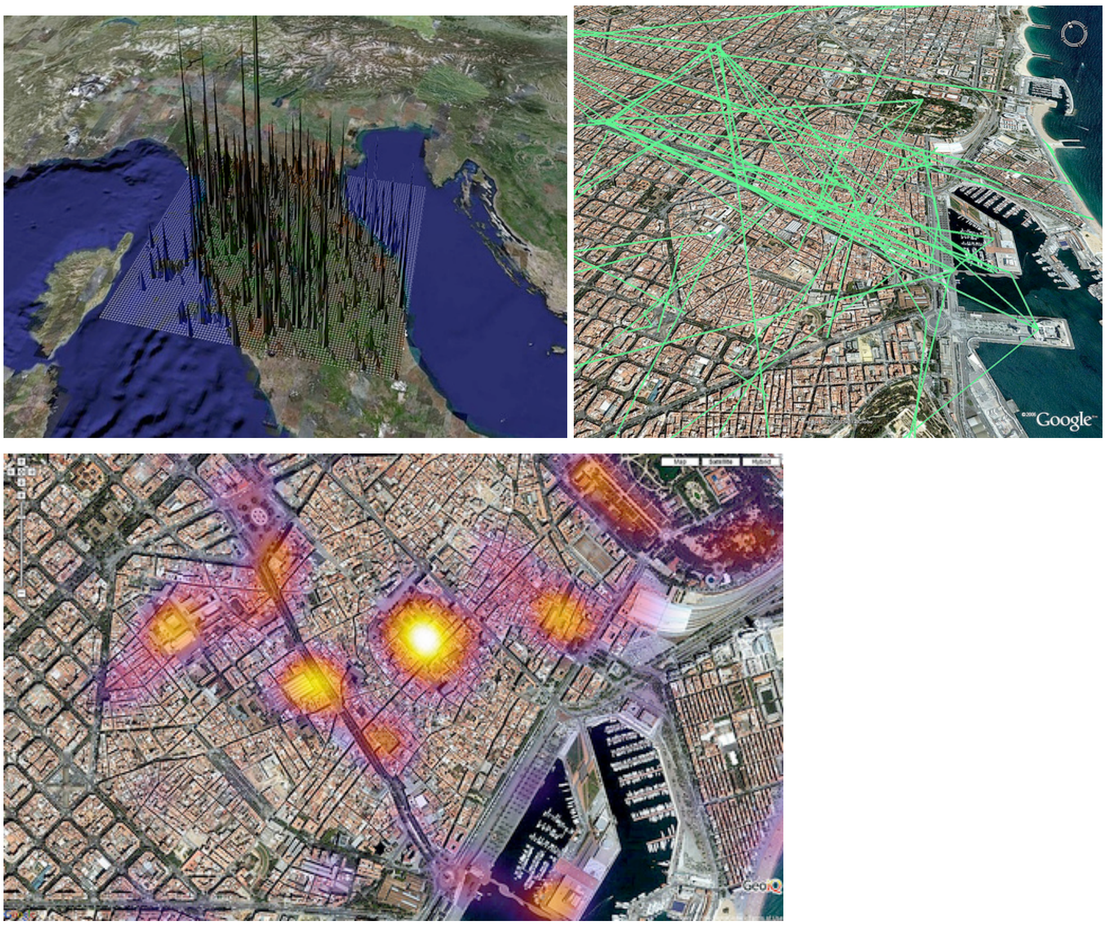


Fig. 8. Geovisulations of the digital footprints left of by the users of Flickr. (a) overall activity in the region of Florence, (b) movements over the course of three weeks in Barcelona, (c) hot spots created by the photos with the fine-grained location in the Barcelona city center. It reveals the city's landmarks. *Photographic imagery copyright 2007 Cnes/Spot, NASA, DigitalGlobe and TerraMetrics.*

2.5 Take-aways

In this section, we provide a few take-aways from our first and current research that we believe to be valuable to design future investigation on the social-technical gap in location-aware computing (i.e. by incorporating understandings of how social practice emerges, we can build systems that fit more easily into the ways in which we work)

#1: Difficulty in interpreting the uncertain information conveyed by location-awareness tools. In CatchBob!, when a teammate was not making any progress, participants were disconcerted because there was not enough information to understand what the problem was. Similarly, they questioned the quality of the system when noticing the system failing to deliver a valid position fix and when experiencing connectivity issues with the network. This kind of uncertainty in interpreting location information can lead to detrimental effect on users' understanding of the situation.

#2: How the deliver the location information. The position offered or described by technology often does not correspond to the positions people want to refer to when they are conversing. The user could be supported in disambiguating situations with an awareness of the limitations of positioning technologies and their inherent uncertainty.

#3: Context of access to location information. Many contextual factors influence the delivery of coarse-grained over fine-grained location information. We could notice that the different urban settings influence the activity of attaching a location to information. Moreover, taxi drivers actively use their location-aware system in specific moment (when there are no contextual cues to give a sense of direction, getting closer to a targeted destination).

#4 Infrastructure and systems issues we presented emerge from the current state of unevenly distributed and unevenly available ubiquitous technologies. Furthermore, technological advances will hardly eliminate the constraints we dealt with in the near future. Therefore we question the paradigm of seamlessness in pervasive computing. This raises the question of "How can we make the limitations or "quality" of context like location more evident in infrastructures so that they can be used by designers, administrators and end users, either to allow them to compensate for varying quality, or as part of the application?".

#5 Use of spatio-temporal analysis tools: graphical and synthetic representation must be developed to further understand the issues people's actions in the environment (e.g. movement in space) supported by location-aware applications (i.e. location-awareness tools).

Chapter 3

Research context, main concepts and definitions

There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating. Machines that fit the human environment, instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods
Mark Weiser

In this chapter, we contextualize the results presented previously within their research domains as pictured in Figure 1 on page 11. The democratization of location-aware systems takes place in the more general paradigm of ubiquitous computing that revolutionize the interaction of human with a computationally-enhanced physical space. Therefore, we present major concepts influencing the emergence of mobile, wireless and sensor technologies and their integration in our everyday life. First, we lay out the visions behind ubiquitous computing and how it reconfigures the relationship between people and the world around them. The situated nature of location-aware technologies creates a new paradigm of physical and digital interaction in which systems must take into account the dynamism and fluidity of human and social activities. As the computation moves “off the desktop” we need to keep track of where it has gone and grasp the dynamic context of use. As reported in Chapter 2 the context of people’s action often take place on top of unstable technologies and infrastructure.

In addition, evaluating the integration of these new pervasive applications in the real-world demands the development of effective methods. Currently, there are still limitations in applying quantitative and qualitative evaluation methods and doing empirical evaluation with the deployment of more living laboratories.

The global understanding of ubiquitous computing research agendas help ground the main concepts of location-aware computing and their inherent social-technical issues. They impact the requirements to describe the architecture of applications supporting location-awareness. Therefore, we evoke the efforts on making the technologies working but also the research on making them workable and enjoyable. We define location-awareness as the “understanding of the whereabouts and other people’s whereabouts.” It aims at enriching the context of human and social activity by providing answers to the questions such as “where am I”, “where people are” and “what people look”. Moreover, location-awareness can be described in terms of the period of time it covers (i.e. past, present and future state of the environment).

3.1 Ubiquitous computing

3.1.1 Definition

In the early 1990s, Weiser (1993a, 1993b, 1994a, 1994b) suggested that the mainframe and personal computing eras would give way to a to "ubiquitous computing," (or ubicomp), an emergence of embedded physical computing mixed with pervasive wireless networking. The vision behind ubiquitous computing is to "**bring the computer to live out here in the world with people and consequently make them effectively invisible to the user**". It was triggered by the convergence of distributed and mobile technologies and the possibility to make many computers available throughout the physical environment. Nowadays, ubiquitous computing has become a dominant paradigm for computing research and an increasingly prevalent form for the delivery of information services in our everyday activities (Greenfield, 2006). Mark Weiser's agenda of ubiquitous computing has prevailed and continues inspiring current research. It conveys the notions of "disappearing computer" and "invisibility". By invisible tool, Weiser was referring that the tool does not introduce on the consciousness, and therefore letting the user focusing on the task rather than the tool. In other words the disappearing computer means "literally visible and effectively invisible". To match up with this vision, scholars have been aiming at designing calm (Weiser and Brown, 1996) and comfortable environments supported by seamless interaction. European Community's Disappearing Computer initiative in the late 90s and early 2000s and the 2007-2011 plan by the Finish Government to build a ubiquitous information society are large scale examples of current efforts in that line of thought. These efforts led to fruitful research in context-awareness, ambient intelligence and monitoring/tracking. However they have yet failed to reach Weiser's vision. Indeed, to this date, there is an enormous gap between the dream of calm, informed and effortless living and the accomplishment of ubiquitous computing research (Rogers, 2006). For instance, many of the sensor technologies, have been beset with detection and precision limitations, sometimes resulting in unreliable and inaccurate data, impairing the ability to deliver what is assumed their users want or need. Similarly, from their observation of the imperfect infrastructure of our everyday life, Mainwaring et al (2004) suggest that connecting to a ubiquitous system often brings with it the risk of noise. This noise may be in the form of nuisance, as when the infrastructure delivers the unwanted along with the wanted. They conclude that *calm ubicomp – even calm, secure, reliable, univocal ubicomp — may not be sufficient, at least not in a context of concerns over temptation and self-doubt in one's self-control*. Based on their extensive work Dourish and Bell (2006) come with similar conclusions and notice *that the rhetoric of seamlessness is often opposed to the inherently fragmented nature of social and cultural encounters with spaces*. In fact, they argue that research in ubiquitous computing provides understanding on how ubiquitous systems support rather than erase these distinctions. Rogers (2006) follows the same train of thought and suggest that *ubicomp technologies should be designed not to do things for people but to engage them more actively in what they currently do*.

However, when we look outside the research laboratory, some aspects of ubiquitous computing are already here; it simply has not taken the form that we originally envisaged and continue to conjure in our visions of tomorrow (Bell and Dourish, 2006). For instance, the RFID-based payment system Octopus is used by 95% of Hong Kong citizen. Our study of taxi drivers and their wide adoption of

GPS-enabled navigation systems aims at understanding the current interactions logical of the "ubiquitous computing of the present" to better envision the future.

From a Human-Computer Interaction stance, ubiquitous computing has their main objectives:

- Conceiving of a new way of thinking about computer and in doing so reconsider the relationship between people and computer
- Develop technologies that are embedded into the environment and in doing so require us to focus on how people will interact with the environment
- Develop techniques to allow computers seamlessly fit into the world at large in order to reduce the cost and overhead of interaction

The following section considers a non-exhaustive set of human and social elements in ubiquitous computing that relate directly or indirectly to our research plan described in Chapter 4.

3.1.2 The human and social challenges

We are still at what Mark Weiser mentioned as Phase I of ubiquitous computing, that is the period to construct, deploy and learn from computing environment consisting of tabs, pads, and boards (ref). Even if fruitful progresses have been made, we are currently involved in that pre-productive phase of evaluating our technologies, considering the social issues and in evaluating the impacts. Moreover, in many situations we must prove the utility of ubiquitous computing solution. In fact, we navigate a delicate balance between predicting how novel technologies will serve a real human need and observing authentic use and subsequent co-evolution of human activities and novel technologies. However, there has been surprisingly little research published from an evaluation or end-user perspective in the ubicomp community (Abrow et al. 2002). In the following, partially inspired by Banavar et al. (2002) we describe some important technical, human and social challenges inherent to the design of ubiquitous systems: the dynamism and fluidity of human and social activities, the instability of the real-world, the design of natural interaction and the evaluation for these new types of design.

3.1.2.1 Dynamism and fluidity

Human and social activities are fluid and nuanced. Two cognitive models frame fluidity and improvisional aspects of task execution. Situated action (Suchman, 1987) models **knowledge in the world continually shapes the ongoing interpretation and execution of a task**. Ubicomp's efforts informed by a situated action also emphasize improvisational behavior and would not require, nor anticipate, the user to follow a predefined script. Activity theory (Nardi, 1996) recognizes concepts such as goals (objects), actions, and operations. However, both **goals and actions are fluid, based on the world's changing physical state instead of more fixed, a priori plans**. In consequence the adaptation to the people's everyday practices and dynamism of their environments becomes extremely challenging. The ubicomp's efforts informed by activity theory, therefore, focus on the transformational properties of artifacts and the fluid execution of actions and operations. Practically, applications that want to adapt to the dynamism of the users' environments might results in uncertainty in the interaction. Sometimes, application won't make the proper inferences, relying on the user active reconfiguration of the system to adapt to the new task settings. In consequence, applications will have to be able to explain what they inferred and learned from their right and wrong inferences (Bellotti and Edwards, 2001). Technically, it demands the development of ontologies to describe users' task environments, as well as their goals, to enable reasoning about a user's needs and therefore to adapt to changes.

3.1.2.2 Unstable and messy infrastructures

The rhetoric of ubiquitous computing traditionally ignores that computing experience must be implemented on top of, and experience in and through, unstable, uneven and not given infrastructure. Building on the assumption that the world is seamless might lead to a miserable failure in integrating pervasive technologies. In fact, technologies such as mobile telephony offer widespread coverage, but are neither truly ubiquitous nor truly seamless. In addition, its deployment and usage suffers from incompatible standards, device heterogeneity and spotty coverage. For instance Morla and Davies, (2006) thoroughly describes the interferences between system and how component's behaviour in a deployed system differs from its behavior when in isolation. From an exploratory field study Mainwaring et al (2004) provide an interesting demonstration of how infrastructures often taken for granted by "users" draws important questions, practices and problems that can be useful to reflect on in ubiquitous computing design. By making similar observations of unevenly distributed, and messy infrastructures, Bell and Dourish (2006) suggest **that dealing with the messiness of everyday life should be a central element of ubicomp's research agenda**. But postulating a seamless infrastructure is a strategy whereby the messy present can be ignored, although infrastructure is always. These imperfection and limitations influence the development of applications and their capabilities. Consequently, the development of software infrastructure requires providing reasonable functionalities with bad connectivity, must recover from failure, and must be scalable. The challenge, then, as we see it, is for ubicomp systems that seek not to automate or even augment/amplify human skills but to exercise and celebrate them, to encourage active engagement, and provide resources to individuals and communities for continuous change and exercise (Mainwaring et al, 2004).

3.1.2.3 Interaction design

A new interactive paradigm has emerged from the situated nature of ubiquitous computing technologies. First, the overall experience merges physical and digital interaction. In other words, the actions on physical objects have meaning electronically and vice-versa. Second, there are different scales of interaction from small devices to large-scale spaces. Weiser (1994) referred to three basic types of scales: inch, foot and yard. Third, there are multiple types of inputs (e.g. sensors, recognition). As mentioned by Abrow et al. (2002), the new means of interaction allow a shift toward implicit from explicit means of human input to more implicit form of input. "*In other words our natural interactions with the physical environment provide sufficient input to a variety of attendant services, without any further user intervention****. For example, walking into a space is enough to announce your presence and identity in that location***." In addition, designers can get access to different types of output to augment the physical world with digital information. The communication from the environment to the user – the output - has become highly distributed. **The challenge is to coordinate across many output locations and modalities without overwhelming our limited attention spans**. As expressed by Satyanarayanan (2001), proactivity is a double-edged sword. Unless carefully designed, a proactive system can annoy a user and thus defeat the goal of invisibility. How does one design a system that strikes the proper balance at all times? Self-tuning can be an important tool in this effort. A mobile user's need and tolerance for proactivity are likely to be closely related to his level of expertise on a task and his familiarity with his environment. A system that can infer these factors by observing user behavior and context is better positioned to strike the right balance. However, there are potential pitfalls in the design trade off between simplicity in appearance and simplicity in use Norman (2002) that might lead to the notion of "clumsy automation" (Wood, 1997)

The new interactive paradigm creates design opportunities (Ark and Selker, 1999) as well as challenges in analysis the interactive principle needed to underpin theses new opportunities. Several design strategies put the needs of people at the core of our understanding and construction of ubicomp environments such as design for appropriation (Baecker et al, 1995), seamful design (Chamlers and MacColl, 2003) and design for emergence (Vogiazou et al, 2007). However, the development of these new strategies to manage ubiquitous computing experiences requires an understanding of the situated nature of technologies and how people relate to these technologies. The following section describes the approaches to develop a formative view to development of where technologies are understood in the real world.

3.1.2.4 Evaluation

Ubiquitous computing takes place in the context of our everyday life. The utility of some computing advancements cannot be evaluated without performing significant user studies and in some cases, widely deploying it. This raises the challenges in understanding and analyzing interaction in the real world alongside the way in which the underlying system senses and understands this interaction. In consequence, the development of effective methods for testing and evaluating the usage scenarios enabled by pervasive applications is an important area that needs attention from researchers. Abrow et al. (2002) mention that there is still the question of how to apply qualitative and quantitative evaluation methods and doing empirical evaluation with the deployment of more living laboratories. The shift into the everyday computing demands new qualitative and quantitative evaluation methods. As a consequence, ubicomp evaluation at this point is more craft than science (Abrow et al. (2002)). Table 3 summarizes the three main evaluation techniques employed.

Table 3. Evaluation techniques in ubiquitous computing

Data collection technique (approach)	**Description**	**Advantages**	**Limitations**
Observations, surveys, questionnaires, interviews (mixed)	Asking users what they think or observing them	Inexpensive was to get lost of information.	Issue of self-reporting after the fact.
Controlled empirical studies (quantitative)	Determine the impact of design parameters on user experience.	We cannot always predict the impact of the system before it exists.	Lack of ecological validity (lab different from the real world)
Experience sampling (mixed)	"Interrupt" everyday life to gather relevant information. Originated as "beeper studies"	Good when you can't be there to observe or record. Gather ecological valid information form end-users. Both before and after the deployment	Interruptions might impact the user appropriation of the system

In addition to these evaluation techniques, ethnography has emerged as a primary approach to address the need to gain rich understandings of a particular setting (e.g. long term study of setting) and the everyday practices that encompass these settings (Crabtree, 2003). Examples of applying ethnography to inform design of social communication range from location-awarness (Deaman et al., 2005), group communication (Axup et al., 2005), construction of social order (Licoppe and Inada, 2005), and collaboration (Benford et al., 2005). Often, ethnography is seen as an approach to field investigation that can generate requirements for systems development. However, a bullet list of design implications formulated by an ethnographer is not the most effective or appropriate method. Ethnography provides insight into the organization of social settings, but its goal is not simply to save the reader a trip; rather, it provides models for thinking about those settings and the work that goes on there (Dourish, 2006).

By pushing on the deployment of more living laboratories for ubicomp research, the science and practice of HCI evaluation will mature. The emergence of experience sample techniques shows that the advancement in ubiquitous technologies can help the evaluation of user interactions in real-world settings (Crabtree et al., 2006).

3.1.3 Context

Context plays a central role in ubiquitous computing, because now that computation is moved "off the desktop", then we need to keep track of where it has gone (Dourish, 2004). Moreover, context-aware systems mediate between people (Belloti and Edwards, 2001). Ubiquitous system must therefore be able to implicitly grasp clues about their environment and act as a common ground for its users. Schilit et al. (1994) emphasize three important aspects of context: where you are (spatial context), who you are with (social context), and what resources are nearby (information context). They also suggest that one has also to take into account technical aspects like communication band-width, network connectivity, speed of user and further the social situation or weather conditions. Further classifications are given by Abowd et al. (1999) and Dey (2001).

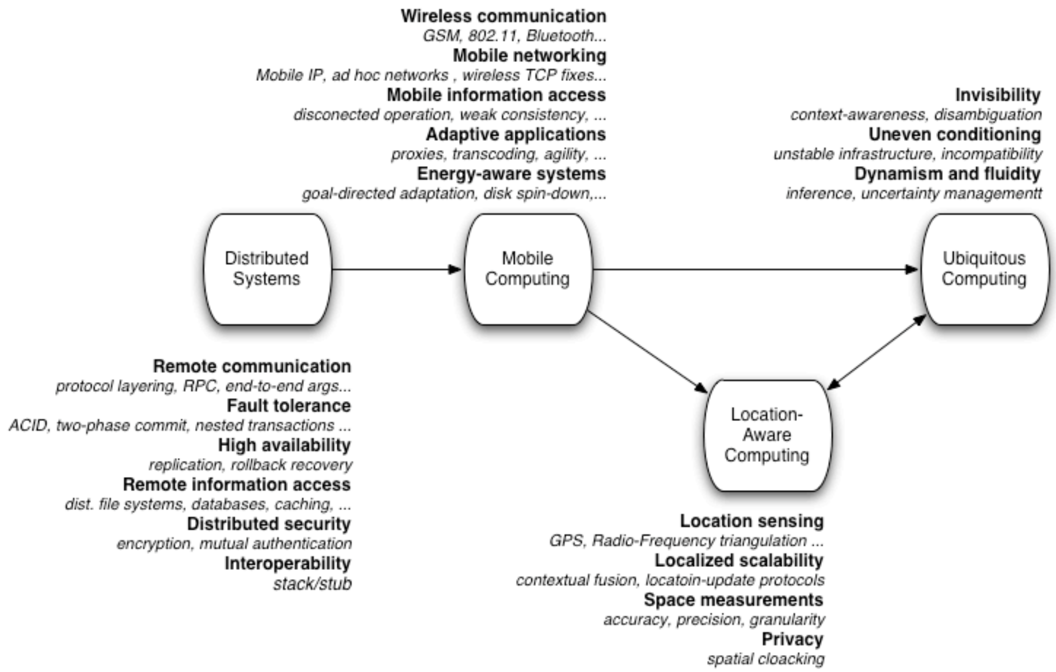
The recent literature offers several definition of context-awareness. Dey (2000) proposes **context-awareness as any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application including the user and applications themselves**. Chalmers (2004) mentions that the formality and rigidity of computational representations of context fails to acknowledge the social construction of context in interaction. He suggests that the problem is that it tends to emphasize objective features that can be tracked and recorded relatively easily, and to de-emphasize or avoid aspects of the user experience such as subjectivity perceived features and the way past experience of similar contexts may influence current activity. Moreover one key issue has been how systems can represent cooperation and its context without over-formalizing, over-simplifying and over-objectifying it. Furthermore, formal procedures potentially can ignore (and even damage) the informal practice. Alternatively, a CSCW approach of context puts focuses on intersubjective aspects of context, constructed in and through the dynamic of each individual's social interaction, and defends against reductionism and objectification (Chalmers 2004). In this perspective, Dourish (2004) shifts the attention of context from "a set of descriptive features of settings" (representational problem) to "practices - forms of engagement with those settings" (interactional problem). He focuses **"*how can people create their own meaning and uses for the system in use*" instead of the very engineering vision of "*how can people get their work done*".**

3.2 Location-aware computing

The possibility to support the representation of location and partners' whereabouts in the physical environment has been one of the leading trends in ubiquitous computing. Location-aware computing emerged from the evolution of mobile computing, location sensing, and wireless networking (Figure 10). It reaches a new level of complexity, as the whole of all the technical challenges is much greater than the sum of the part of issues raised by distributed system and mobile computing. Mobile computing is commonly associated with small form-factor devices such as PDAs and untethered (wireless) connectivity. Such devices provide access to information processing and communication capabilities but do not necessarily have any awareness of the context in which they operate. Location-aware applications respond to a user's location, either spontaneously (e.g., warning of a nearby hazard) or when activated by a user request (e.g., is it going to rain in the next hour?). Figure 9 shows the canonical example of a location-awareness application. It refers to system ran on mobile devices that are often multi-users and provide services such as tracking of others locations (loved ones, objects, pets) or tagging the environment.

Fig. 9. Canonical example of a location-aware application

Location-aware computing is primarily an engineering driven research field. The main research agendas focus on sensor technologies and location techniques. The themes cover the opportunities and issues in the accuracy, coverage, autonomy, privacy, interoperability, data modeling, middleware, positioning algorithms, robustness, uncertainty, cost, ubiquity, and scalability.



This figure shows how research problems in location-aware computing relate to those in ubiquitous computing, mobile computing and distributed systems. New problems are encountered as one moves from left to right in this figure. In addition, the solution of many previously-encountered problems becomes more complex. It is very much more difficult to design and implement a location-aware system than a simple distributed system of comparable robustness and maturity. Note that this figure describes logical relationships, not temporal ones.

Fig. 10. Taxonomy of computer systems research problems in Location-Aware Computing

The reminder of this chapter will highlight some of the technological research problems in location-aware computing with the consideration to the human and social effects.

3.2.1 User expectations

Kaasinen (2003) studied location-aware mobile services from the user's point of view. He draws conclusions about key issues related to user needs, based on user interviews, laboratory and field evaluations with users, and expert evaluations of location-aware services. This work reveals users needs in context of use, temporal use, information scope and privacy:

- **Location-aware information was expected to be especially useful in special situations**, e.g. in unfamiliar environments, when looking for a specific service or in emergency situations (spontaneous and occasional use). These needs indicate that the services should be easily available when the spontaneous need for them arises.
- **It is not wise to restrict the available information only to the current location and time**: the users may also need to plan their next activities or to return to previous activities.
- Ideally the user should **see all the necessary information for a given task in a single view**. In practice, people may not be willing to spend their time on something from which they do not get immediate benefit.

- It did not occur to most users that they could be located when using location-aware services. Need to be able to use the mobile system both on and off line.

3.2.2 Activities and applications

This class of application, enabled by location-aware technologies has been exemplified by early prototypes such as "Active Badge" (Want et al., 1992) which proposed to transmit and represent the real-time location of a badge carried by a person in a building. In the last fifteen years, this topic has received a large amount of attention by researchers in ubiquitous computing (see Benford, 2005 for a review) and some commercial products that support this awareness of others' location are now running on state-of-the-art cell phones (e.g. Plazes[3] or Dodgeball[4]) or in-car GPS (e.g. TomTom Buddies).

However, the applications catalogued as "location-aware" technologies or "location-based services" are still broad and diverse. They often refer to both applications that convey information about others' location in space as the one mentioned above and annotation systems that allow the association of digital information to physical locations (Espinoza et al., 2001 for example). Some of them, such as in-car GPS-enabled systems, can be used individually and some others are multi-users. The latter are often referred to as 'mobile social software' or 'social location-aware applications'. Reichenbacher (2003) proposes a classification based on the supported actions (Table 4). It allows to distinguish the different classes of applications and interfaces. In this **work we mainly focuses on what we termed "location-awareness": providing facilities for orientation and localization, that is applications supporting location-awareness** (i.e. providing answers to the question Where am I?

[3] http://www.plazes.com

[4] http://www.dodgeball.com/

Table 4. Taxonomy of location-aware application based on the possible actions (Reichenbacher 2003).

	Action	**Question**	**Operation**
	**Orientation and localization** (location-awareness)	Where am I? Where is (person/object)	Positioning, geocoding, geodecoding
	**Navigation** (navigating through space, planning a route)	How do I get to (place/name/address/coordinates)?	Positioning, geocoding, geodecoding
	**Search** (searching for people and objects)	Where is the (nearest/most relevant) - (person/object)?	Positioning, geocoding, calculating distance and area, finding relationships
	**Identification** (identification and recognizing persons and objects	What/who/how much) is (there/here)?	Directory, selection , thematic/spatial, search
	**Event check** (checking for event; determining the state of objects	What happens (here/there)?	

3.2.3 Location-awareness

'Awareness" is a well-known notion in Computer-Supported Collaborative Work (CSCW) that Gutwin and Greenberg (2002) defined as the "up-to-the-moment understanding of another person's interaction with the shared workspace". The set the general dimensions of awareness around the "Who, What Where, When" questions. For example answering the "what" question enables to define what actions are performed, the goals and the artifacts that are deployed. More precisely, according to these authors, awareness refers to the perception of changes that occur in the shared environment. Gutwin and Greenberg also highlight that awareness is not only to perceive information but also to recognize the contextual elements required to carry out a joint activity. This is what Dourish and Belloti (2002) expressed by defining awareness as "an understanding of the activities of others, which provides a context for your own activity". These definitions emphasize the idea that awareness is meant to enrich the context of a social activity such as collaboration. In the case of location-awareness we are interested in the spatial (Where) and temporal (When) aspects of "awareness". An answer to the where question (e.g. "where people are" or "what people look/what can they see") can take different forms depending on how the location information is conveyed for example a text message that indicates a person's whereabouts or dots on a map. Moreover, location awareness can be described in terms of the period of time it covers, conveying information about the present state of the environment ("synchronous awareness") and or about past occurrences of events ("asynchronous awareness"), which corresponds to the "When" question.

For instance information supporting location awareness are often exchanged in cell phone conversations. Providing or asking for geographical information constitutes a highly frequent part of the conversation opening with a phone call: "Where are you?" often comes immediately after "How are you". Various studies have explored this phenomenon claiming that it allow dispersed cell phone users to mutually establish and share a spatio-temporal context (Laurier, 2001) or allow group coordination for meetings (Weilenmann, 2003). Arminen (2006) points out that giving one's location in mobile telephony can also be "an index of interactional availability, a precursor for mutual activity, part of an ongoing activity, or it may bear emergent relevance for the activity or be presented as a social fact". Given the importance of this phenomenon, Arminen claims that a technical solution to indicate location-awareness would have a wide applicability for a majority of mobile users.

3.2.3.1 Position, space and place

To support location-awareness applications must go beyond providing coordinates as human beings generally favor the notion of "place". A recurrent discussion concerning spatiality targets the differences between the concepts of "space" and "place". Harrison and Dourish (1996) indeed advocated for talking about place rather than space. They claim that even though we are located in space, people act in places. This difference opposes space defined as a range of x and y coordinates or latitude/longitude to the naming of places such as "home" or "café". A place is general a space with something added - social meaning, convention, cultural understandings about role, function and nature and so on. By building up a history of experiences, space becomes a "place" with a significance and utility; a place affords a certain type of activity because it provides the cues that frame participants' behavior. In a sense, it is the group's understanding of how the space should be used that transform it into a place. Space is turned into place by including the social meanings of action, the cultural norms as well as the group's cultural understanding of the objects and the participants located in a given space. However, as Dourish (2006) recently claimed, this distinction is currently of particular interest since technologies pervade the spatial environment. This inevitably leads to the intersection of multiple spatialities or the overlay of different "virtual places" in one space.

Thus, location-awareness of others also relates to how people make sense of a specific location: depending on the way the location of others is described; it could lead to different inferences. For example, knowing that a friend is at the "library" (place) frames the possible inferences about what the friend might be doing there.

However, applications reasoning about ``place'' rather than coordinates rely on manually defining places which, while useful, do not scale to ubiquitous deployment. Users must, by hand, delineate and label their neighborhood, property, rooms, furniture, and service areas. This poses two challenges (Hightower, 2003). First, analyzing movement data to, over time, suggest geometric regions that are good candidates to label as places. Second, automatically label the place by inferring people's activity or aggregate the labels periodically disclosed by many people. Hightower et al. (2005) introduced the Beacon-Print system that uses WiFi and GSM radio fingerprints collected by someone's personal mobile device to automatically learn the places they go and then detect when they return to those places.

The difficulty of location-based applications in conveying a meaningful semantic of places makes it more efficient to let users express their location by using their own description, a topic already discussed by Persson and Fagerberg (2002). This finding, on the benefits of manual location disclosure, is confirmed by what Benford et al. (2004) revealed: self-reported positioning could be reliable low-tech alternative to automated systems like GPS. In addition letting users declare their position themselves is better with regards to various processes like communication or the construction of a mental model about the partners (Nova, 2007).

3.2.3.2 Privacy

The emergence of positioning technologies raises major privacy concerns (Hong, et al, 2003). Location privacy that Beresford and Stajano (2002) defined as "the ability to prevent other parties from learning one's current or past location" is thus harmed by sensitive timely and positional information. This then leads to difficulties in the social acceptance of location-aware systems in terms of user rejection or reluctance to employ certain features. A possible answer to these concerns is to provide abilities to control the access to location disclosure with different levels of permission and allow the deniability of communication (e.g. opting out of the system). This can be solved with spatial cloaking techniques (Gruteser and Grundwald, 2003) to obscure the quality of the data. Moreover, users should know when they are in the system and when not (Greenfield, 2006). If could also supporting the possibility to lie

The fact that awareness threatens privacy has been acknowledged both for virtual environments and ubiquitous computing (see Bellotti and Edwards (2001) on this topic) since both enable the capture and storage of people's positions and their activities. This relates to the long-term debate in the CSCW field about the balance between awareness and privacy intrusion (Hudson and Smith, 1996). Designers of multi-user applications face the problem of providing enough information transmitted to others (so that they can benefit from it) without threatening the protection of users' privacy. Ljungstrand (2001) and Ackerman et al. (2001) show how a certain level of privacy loss can be accepted if the benefits perceived are sufficient enough.

These authors highlight the importance to preserve imperfect sensing and communication of location information

3.2.4 Architectural overview

The design of location-aware application implies connecting together different layers of technologies. Measurements of the physical space rely on sensors, the exchange of the data on middleware and the communication of the location information through interfaces. Hightower et al. (2002) and Graumann et al. (2003) present these layers in the form of a "Location Stack" inspired by the Open System Interconnect (OSI) model to encourage the designers to think of their application in this way. They focus on what can be captured, what each layer can be delivered. Schiller and Voisard (2004 p. 22) describes a similar three-tier communication model with a positioning layer, a middleware layer, and an application layer We inspire from these layer-based vision of ubiquitous location-aware systems, by mixing the technological focus with the user experience of location-aware computing. Therefore, we categorize three components that influence the expectations as well as the interpretations of location information. As represented on Figure 11, the participants' location need to be captured by sensors, it gets communicated middleware capabilities (e.g. location update protocol, exchange data format), then retrieved and delivered in a certain way via a user interface.

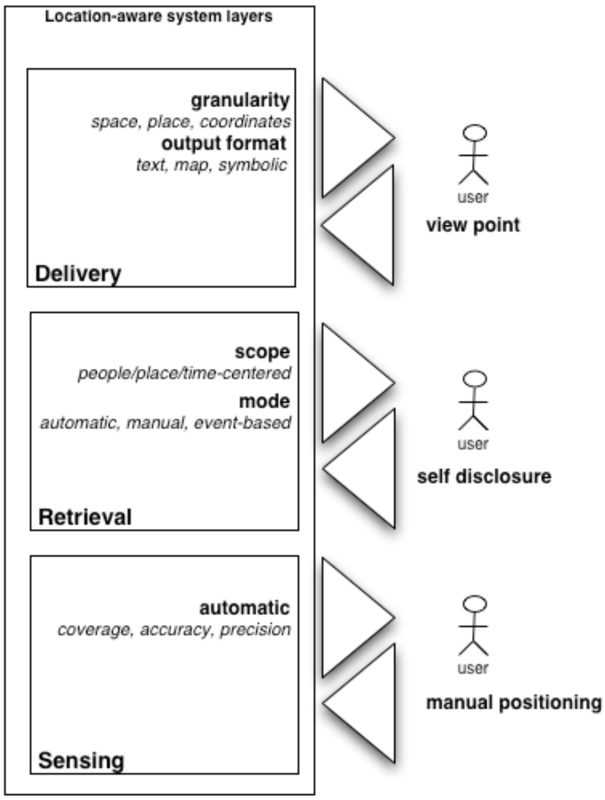


Fig. 11. Architectural layers of location-aware systems

The following three sections aim at clarifying the context and concepts behind each layer.

3.2.5 Location-sensing

Location-sensing technologies aim at capturing a position in the physical space. As mentioned previously, no single positioning system fulfills all the needs of all the needs in terms of coverage and precision. Each location system generally has both unique characteristics and limitations in term of technology. In addition to what we account in Chapter 2, many field studies reported on the practical lessons (e.g. accuracy, robustness, uncertainty, cost, privacy, scalability) of delivering real-world ubiquitous location systems (Hightower et al., 2006; Borriello et al., 2005). Some focused on the fluctuant accuracy and ubiquity issues of WiFi (Cheng et al., 2005) and GSM (Chen et al., 2006) in urban environments.

Nevertheless, they can be compared from the common features in the properties (Figure 12) of the location data they deliver. In their overview of location-sensing techniques, Hightower et al (2001) defines some distinct properties: the possibility to provide physical position (coordinates) or symbolic location (“home”, “a car entering Los Angeles”), the difference between absolute and relative positioning (depending whether the frame of reference is shared or not), the accuracy (the grain size of the information that can be provided) and the precision (the odds to obtain that accuracy). Hazas et al. (2004) expand on that topic by making the distinction between coarse-grained systems and fine-grained ones. Roth (2004) extends the list of properties to the scope (an area of potential coordinates) and coverage (the area of potential location specified by the scope).

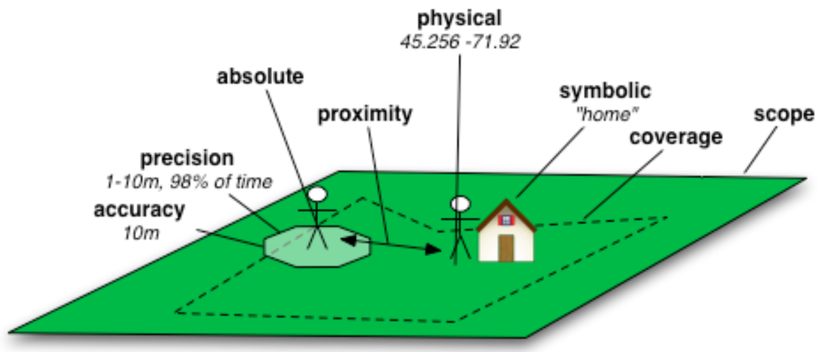


Fig. 12. Location sensing features

The technological features create a wide range of systems to determine the location of a mobile user. They can be categorized in different ways depending on their techniques and methods to determine a location. For instance a *tracking* system relies on a sensor network while a *positioning* system determines the location itself. Then various basic technical can be applied:

- Cell of Origin (in wireless environments, the transmitting cell has a certain identification that can be used to determine a location),
- Time of Arrival (proximity measurement from the time difference between a sender and a receiver),
- Angle of Arrival (direction characteristics from the arriving signal),
- Measuring the signal strength (intensity of electromagnetic signal at arrival at the receiver),
- Fingerprinting (Otsason et al. 2005, correlation with past observations),
- Processing video data (detecting moving patterns from video data stream).

In addition, geometric approaches might be used to compute the coordinate of a location: Triangulation (measurement of the angle to the location from two fixed positions), trilateration (similar to triangulation but with distances to the unknown location, and tranversing (uses several distance-angle pairs). Finally, Roth (2004) proposes three classes of positioning systems: satellite positioning system, indoor positioning systems and systems that use an existing network infrastructure. Table 4 summarizes the main approaches for each of these categories.

Table 5. Approaches to location-sensing for each class of positioning system

Class of positioning systems	Approach	Example
Satellite positioning systems	Global Positioning System (GPS), Galileo, Assisted-GPS	Sirf[5]
Indoor positioning systems	Infrared beacons	Active Badge (Want et al, 1992)
	Ultra-wideband	Ubisense[6]
	Radio Beacons	SpotOn (Hightower et al., 2000)
	Home infrastructure	ActiveFloor (Addlesee et al. 1997) Powerline: (Patel et al., 2006)
	Video-Based systems	(Rungsarityotin and Starner, 2000)
	Ultrasound	Active Bats (Ward et al., 1997)
Network-based positioning systems	GSM:	Varshavsky et al. 2006
	Wireless LAN:	Ekahau[7], RADAR (Bahl and Padmanabhan, 2000), Place Lab (La Marca et al., 2005), Skyhook[8]
	Digital TV signals	Rosum[9]

3.2.5.1 Sensor fusion

As mapped by Hazas et al. (2004) (see Figure 13) there is a wide diversity of location-sensing technologies distinguishable accorded to their range of accuracy and their predicted deployment. To overcome the limitation of each solution, there have been attempt to create common location data sets consisting in geodetic latitude, longitude and altitude, accuracy and time of measurement, speed, direction, course, and orientation. The task of making sense of this vast amount of sometimes contradictory information, known as sensor fusion, presents a major challenge. Borrowing from the field of robotics, location researchers have settled on Bayesian inferencing as the preferred method for processing data from disparate location sensors. The result is a location measurement derived from multiple sensors and constraints that uses a probability distribution rather than a single value to describe the inherent uncertainty. The MIT Cricket project (Priyantha et al., 2000) at demonstrated an indoor location-measuring system that processes data from multiple sources, including Radio Frequency and ultrasonic sensors, using a particle filter. Similarly, the Place Lab projects uses the fusion of GSM, WiFi and GPS positioning the increase to aim at an ubiquitous coverage both in outdoor and indoor environments. Welbourne et al (2005) reports on the fusion of location and non-location sensors data to leverage the synergy between them to enable a wider variety of high-level

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[5] http://www.sirf.com/

[6] http://www.ubisense.net/

[7] http://www.ekahau.com/

[8] http://www.skyhookwireless.com/

[9] http://www.rosum.com/

mobile context inference. Finally, PLACE's approach (Linh et al., 2002) is to reason about locations as semantic places rather than coordinates. The problem is that there can be many different representations for the same location and having syntactically identical representations for different locations.

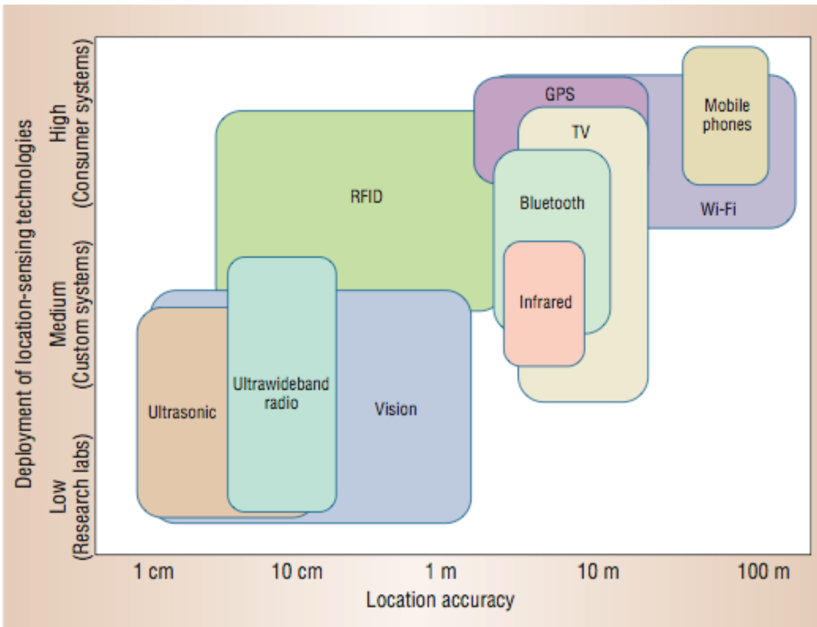

Fig. 13: Location-sensing technologies. Each box's horizontal span shows the range of accuracies the technology covers; the bottom boundary represents current deployment, while the top boundary shows predicted deployment over the next several years. (Hazas et al., 2004)

3.2.5.2 Manual positioning

The advantage of an automatic capture is first and foremost because the administrative burden is lighter for the user. Through the automation of the capturing process, he or she does not have to choose the location information and find how to send it to the peers. However, there are benefits for a location-aware system to rely on the user to fix his or her own (Iachello et al., 2005). Compared to automatic positioning in which location is just information, self-declared positioning is both an information and an act of communication act, intentional by definition. In other words, self-disclosed location add some intentional weight that help providing mutual intelligibility to communication because people gives information they estimate as being relevant for their partners. Another advantage for self-disclosing one's location is that it allows people to employ the location names that make sense for the participants.

Finally, the last advantage of self-disclosure of one's location is that it may allow to communicate one's future location. Fahlén et al (2006) describes a physical device that enables user to turn a knob to see the past location of family members (captured through GPS reporting and radio beacons scanning) as well as their planned location. The inherent intentionality of such messages about future location is beyond grasp of technological means, even though automated systems are being developed to infer and predict certain trajectories like driving behavior (Krumm and Horvitz, 2006).

3.2.6 Location retrieval

At the core of every location-aware system is the “plumbing” that manages the interactions between the sensors, devices and their interfaces. Such infrastructural systems are expected to deliver the correct information, at the correct time, to the correct place, in the correct format. However, they often rely on the limited available resources to provide the best services. This impairs the mediation between the hardware, software on a network and in the interface. For instance latency on the network might decay the information and it might be too late to do anything about it. The scale, synchronicity and language (protocol, RDF) is handled by a so-called middleware that takes care of the transparent communication between the components of a location-aware system (sensor, database, server logic, wireless network, client application. Examples of middleware in context-aware computing are GAIA (Román et al., 2002) and Construct (Wiil, 2002).

The middleware should be able to contextualize interaction in order to adapt the infrastructure, information, or its delivery, to the semantics of use. There are mainly three interaction modes to communication location information to a user: upon his or her request, triggered by an event or automatic update.

As we have seen in the preceding section, the point here is also to decide where to the agency of the system: should the user ask for information (pull), is it preferable to delegate it to a location update protocol (Leonhardi and Rothermel, 2001) (push) or depend on the change in the state of the environment to trigger new information?

The retrieved location information can be based on different scopes. First, the user can look for information about people (People-Centered: “Display my friends location”) or look who is located in a specific place (Place-Centered: “Who is in that room”) (Jones et al., 2005). In addition, the scope of information that needs to be retrieved can be bound to a specific period of time. This last characteristic corresponds to the difference made in (Gutwin and Greenberg, 2002) between synchronous (information about real-time position in space) and asynchronous MLA (information about real-time and post position in space).

3.2.7 Location information delivery

Although other channel of communications can be employed, the final format of location information delivery is generally displayed visually in 3 ways. It can be verbal (name of a place), symbolic (shown as a symbol), or geographic (depicted on a map metaphor). Each of these approach must take into consideration the display restriction of mobile devices (Chittaro, 2006, Yoo and Cheon, 2006, Look et al., 2005)

3.2.7.1 Text-based

The simplest form of location-awareness is a verbal or text-based description of people's whereabouts. This is obviously the case for explicit disclosure of one's location by cell phone (audio communication, audio message or SMS). Yet, location-awareness can be conveyed verbally by various systems, which automatically capture the user's position (either in virtual or physical space) and display it to the partners with a short sentence, such as a place name. For instance, in the presence-awareness mobile service Jaiku: the information about others' whereabouts is displayed as a line in the phone book updated in real-time (see Figure 14). It is also possible to use a verbal display to indicate the proximity of a person. An example of such mutual location-awareness (MLA) interface is The Hummingbird (Holmquist et al., 2003). An early prototype of location awareness on a pager, this application displays the ID of persons in the vicinity.

Fig. 14. Jaiku: location-awareness with an one-line description in the phone address book

3.2.7.2 Symbolic

A second form of MLA representation consists in displaying people's location as a symbolic representation with "place descriptors" as in the Microsoft's Whereabouts clock shown in Figure 15 (Sellen et al., 2006). Designed for the context of the kitchen, this MLA interface displays family members, essentially for family activities coordination (e.g. planning a meal, knowing whether someone is on his way to home). The clock metaphor is used to provide coarse-grained information such as "home", "school" or "work" and no precise position, which can be irrelevant in the context of the use of this artifact. In this example, information about others' whereabouts is automatically provided by SMS that are sent to a family member when one of them moves from one registered zone ("work" for instance) to another registered one (such as "home").

Fig. 15. Microsoft's Whereabouts clock's prototype depicting family members' location for one day. The discrete locations that have been chosen for this prototype are: "home", "work", "school".

3.2.7.3 Map-based

The third type of MLA interfaces is based on the RADAR paradigm (Radio Detection And Ranging) that displays persons or artifacts present in the vicinity. As a recurrent representation for locating objects in the physical world (e.g. air traffic control, military applications), this paradigm inspired virtual space versions. This type of MLA interface has a relative format of delivery (that we could call proximity awareness), since some elements remain hidden (those which are not in the vicinity). Moreover, even though the "Radar view" (Figure 16a) displays the positions of participants, it does not provide the users with a representation of spatial features like topography or position of area boundaries (apart from circles than indicates distance to the user). The representation is limited to a small portion of the space and is only directed towards the presence of objects and people in the area.

A well-known example of such MLA interface is the "Active Badge" system depicted on Figure 16b.

Fig. 16. Example of map-based location-awareness: (a) Radar view in Mogi-Mogi. (b) Active Campus running on a PDA.

Active Campus (Griswold et al, 2004) interface shows people's positions at the campus level. It proposes a reduced version of the environment with people's location superimposed on top of it. This simplified representation comes form the concept of generalization applied in the field of cartography (Firgue 17). Cartographic generalization is the process of selecting and representing information adapted to a scale to make the schematic map useful (Reichenbacher, 2004).

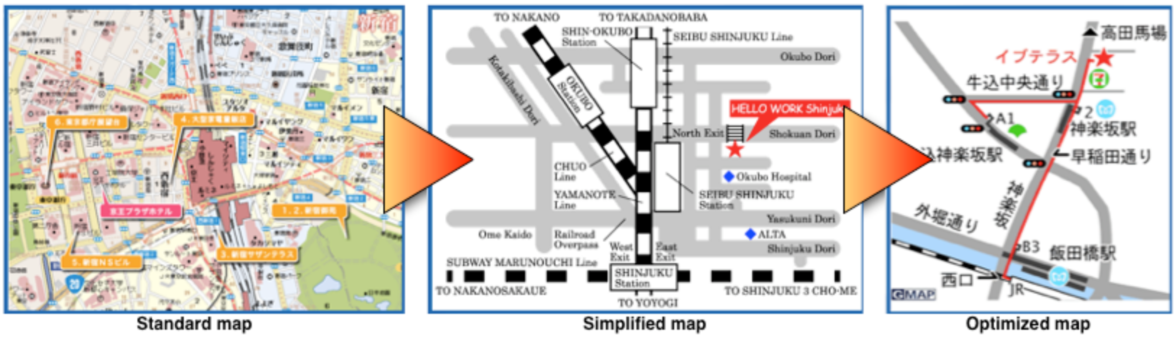

Fig. 17. . Process of generalization: from a standard map to an optimized map. Inspired by Benjamin Joffe's presentation at the Games and Entertainment workshop at the UbiComp 2005 conference.

Maps are about things at particular places and times. Their interpretation leads to the information on the where (location), what (geospatial object, person, activity) or when (time).

When regarding the usability of a map, an important criterion is utility in the sense of being useful for conducting the current activity. There is no consistent terminology for maps that are designed for user activities: egocentric maps, focus maps, aspect maps, topic maps, or activity-based maps. The view taken here is that maps applying adaptation methods as mentioned before can be termed ego-maps, because they are egocentric in the sense that the user is in the centre. This centre can be (1) the spatial centre, (2) the centre of activity, (3)the centre of interest and so on.

These different location-awareness delivery formats can also be defined using two factors defined in (Suomela and J. Lehikoinen, 2004) as the environment model and the viewpoint. The former refers to the number of dimensions employed to visualize the environment ranging from three dimensions (3D model of the environment) to no dimensions (no environment representation). The latter corresponds to the perspective given to the users, whether it is a first-person or a third-person view of the environment. Most of the applications we have described in this section corresponds deploys 1D (Jaiku) or 2D (Active Badge) model of the environment. Regarding the viewpoint, maps propose a "third person view" because the users view both the location- based data and his or her representation. First-person views can be exemplified by a proximity system in which people views the location information about their partners from a user-centric view, and the location-based data is spread around him or her.

3.3 Discussion

In this chapter, we aimed at going deep into the technical and social issues of ubiquitous location-aware computing. Summarize each aspect (privacy, sensing, delivery, interpretation, the technological opportunity, the need to asset it). Incorporating understandings of how social practice emerges, we can build systems that fit more easily into the ways in which we work. Ubiquitous computing forms a very difficult integration of human factors, computer science, engineering, and social sciences. We are reaching a new level of complexity, as the whole of all the technical challenges is much greater than the sum of the part of issues raised by distributed system and mobile computing. Features of ubiquity are highly demanding, including supporting task dynamism, assuring device heterogeneity and providing a holistic user experience in the context of resource constraints.

Location-aware computing allows to access and share spatio-temporal context in mobile settings. The use of location-aware application takes place in special situations (e.g. in unfamiliar environment, coordinating with friends) and should be easily available. The activities performed (orientation, navigation, search, identification, coordination) rarely have a clear beginning or end, interruption is expected as users switch attention, multiple activities operate concurrently and might be loosely coordinated. Moreover, it has issues in terms of privacy and making sense of the context the technologies are deployed in, To support location-awareness, they must communicating the physical space it measure to human notions (space, place, coordinates) (how do we make sense of a specific location). They are deployed in uneven, unstable infrastructures. Location-aware systems are form in three basic layers, location sensing (sensors hardware, sensing techniques, positioning algorithms), location retrieval (middleware, network, protocols) and location delivery (user interface). Table 6 summarizes the main technical and social issues for the design of each layer:

Table 6. Technical and social issues of location-aware computing

Layer	**Technical issues**	**Human/Social issue**
Location sensing	Accuracy, ubiquity	Automatic versus manual location disclosure (Agency). Spatial uncertainty
Location retrieval	Location and context modeling, data exchange protocols. Location timeliness.	Proper user access mode to information is push or pull (agency). Temporal accuracy
Location delivery	Display constraints to information presentation	Match the expected/desired. Location information granularity.

Our work presented in next chapter, aims at investigating some of these socio-technical issues. It shares two of the research avenues suggested by Yvonne Rogers in her seminal paper (Roger, 2006): use ubicomp technologies in the wild, and evaluate how to present data and information:

More studies are needed of UbiComp technologies being used in situ (out of the lab) -- to help illuminate how people can construct, appropriate and use them. With respect to interaction design issues, we need to consider how to represent and present data and information that will enable people to more extensively compute, analyze, integrate, inquire and make decisions; how to design appropriate kinds of interfaces and interaction styles for combinations of devices, displays and tools; and how to provide transparent systems that people can understand sufficiently to know how to *control and interact with them.* It implies the application of both qualitative and quantitative evaluation methods and doing empirical evaluation with the deployment of more living laboratories (Abrow et al., 2002).

Chapter 4
A Research plan

"Let's do smart things with stupid technology today,
rather than wait and do stupid things with smart technology tomorrow"
William Buxton

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 a physical context. Yet, our preliminary work presented in Chapter 2, relates with the limitations and constraints related to the underlying technologies that create a technical-social gap in the use of such systems. Chapter 3 provided the key technical, human and social concepts to understand the issues at stake.

Now, to reduce this gap, we 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. This last Chapter serves the purpose of presenting our future work in that direction. It states two major aspects of the social-technical gap, spatial uncertainty and location information granularity that we believe must be further studied. Based on this problem statement, we selected research perspectives that investigate approaches to understanding and reducing the gap by taking into consideration the imperfection of the location-aware technologies. Finally, we propose an approach and methodology to evaluate our contribution.

The next steps in this research are based on the further investigation of the current use of location information granularity and of the interaction with uncertain spatial information through the two case studies mentioned in Chapter 2. In addition, we 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.

4.1 Problem statement

As we have mentioned previously, the physical, technological, organizational or economical constraints limit use of location-aware technologies 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 revealed in Chapter 2 and investigated in several field studies on location awareness (Benford et al., 2003; Benford et al., 2006; Chalmers and Galani 2004; Girardin et al., 2006), 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 (Benford et al., 2006). 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. This call for a mindset change not to only think about the development of location-aware application from the perspective of a technological opportunity but also through human and social lenses. Answers must be answers such as: why does technology do not always match the expectations? How is it useful and useable? How accurate to be useful? How possible is it to be accurate? What is good enough for your users? How much benefit will they get? What location information do I need/want to wander in space. What are the access modalities and their cost? These questions reveal that we cannot just throw technology at the problems. The following section describes in further details the aspects of the problem.

4.1.1 Social-technical gap

As described by Kaasinen (2003), users of mobile location-aware services expect availability in special and spontaneous situations. This demands technological settings that can support flexible, nuanced, and contextualized social world. However, the user expectations of location-awareness can be easily obscured by the limitations of modeling the subtlety of social settings and problems in terms of service coverage, stability, connectivity, mobility, cost, privacy and accuracy. Bubb-Lewis and Scerbo (1997) mention that users struggle with the shortcomings of location-aware technologies deployed in real-world settings. These observations reveal a social-technical gap known in CSCW "that divides what we know we must support socially and what we can support technically" (Ackermand, 2000).

Computer Science, AI, Information Technology, and Information Science researchers have attempted to bridge the gap without success for at least twenty years. The context gap is inevitable and inherent in that it cannot be bridged; human context can only be represented technologically to a limited extent. (Barkhuus, 2004). It is time to consider that the gap is likely to endure and that we should consider what to do about it. The HCI and CSCW research communities need to ask what one might do (a) to ameliorate the effects of the gap and (b) to further understand the gap.

The combination of CSCW and ubiquitous computing forces social and technical ideas to sit together. However combining them have not yet been achieved. Ubiquitous computing systems may be more responsive, and yet they seem to fail to address the sociological critique. Turning social observation into technical design seems to be problematic (Dourish 2004). Positivist and phenomenological reasoning often fail to reach common grounds. Positivist design, supported by quantitative and engineering techniques seek to reduce social phenomena to essence or simplified models that capture underlying patterns. In particular, the idea that context consists of a set of features of the environment surrounding generic activities, and that these features can be encoded and made available to a software system alongside an encoding of the activity itself, is a common assumption in many systems. It is inherent in the notion that our systems will “capture,” “represent,” or “model” context –

the normal and appropriate concerns of positivist design (Dourish 2004). On the other hand, phenomenological theories are qualitative in orientation and focus on social facts as emergent properties of interactions. There is a need for a degree of reduction and objectification to match the formal representation of technologies. Therefore, we must take a pragmatic stance if we are to design the finite and formal representation that constitute context-aware and CSCW systems. Embodied interaction is a good exemplar of research in CSCW and context-aware computing that begins to bridge between useful practices and strong theory (Chalmers 2004).

This gap forces us to take a pragmatic stance to try to make both fields bridge. Issues are twofold. On one hand formalize context to a degree of reduction and objectification that matches computer systems without undermining the benefits of location-aware systems. On the other hand, make contextual details and system inferences visible (systems that display their content, intelligible and accountable) without overwhelming the user. It does not go in complete contradiction with the ideal of "literally visible, effectively invisible" of ubiquitous computing, because a tool becomes invisible or ready-to-hand through the process of accommodation and appropriation. Therefore, Weiser suggested the we should aim for and support accommodation and appropriation of computing into everyday life (Chalmers, 2004).

One of the high-level goal of further investigation would be to understand/help this appropriation process with an uncertain context in a real-world and uncontrolled ubiquitous environments.

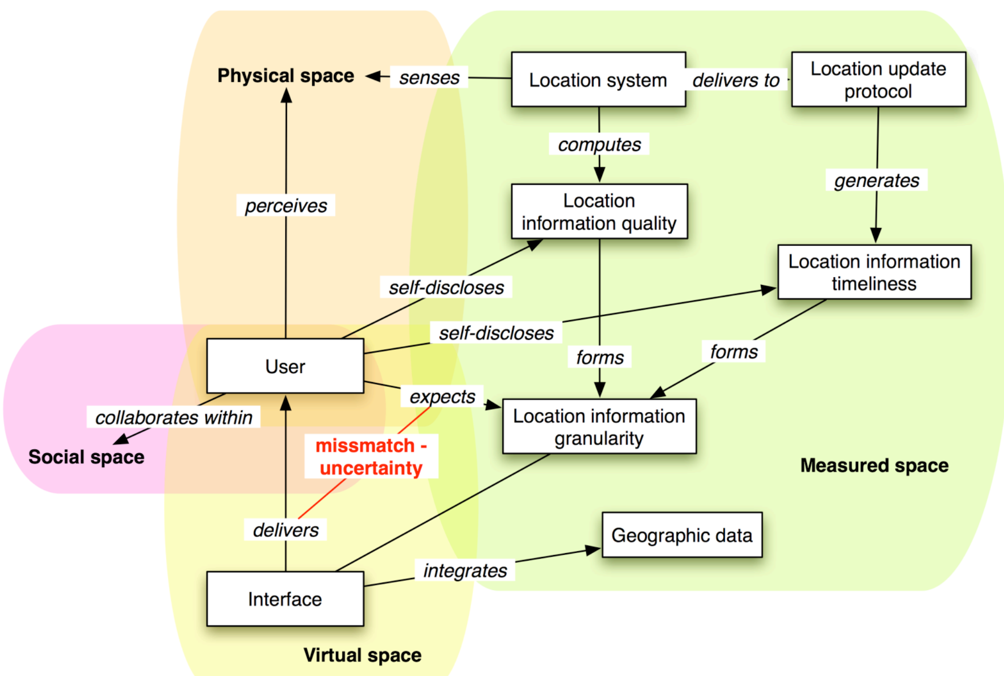

Fig. 18. Model of the social-technical gap in location-aware computing

From our observations (Chapter 2) and a thorough literature review (Chapter 3), we consider/extracted two elements that form the gap. The **spatial uncertainty** inherent to ubiquitous technologies and the **location information granularity** expected by the user of location-aware applications. Uncertainty refers to the feeling of dealing with to incomplete (lack of precision) or incorrect (lack of accuracy) location information. Granularity refers to the level of accuracy given to location information. In Figure 18 models the social-technical gap in location-aware computing with these aspects. It splits in four different spaces where the user of a location-aware application belongs to: he or she lives in the physical space, among peers in a social space. Location-awareness is conveyed by an interface (virtual space) that gives sense to the measurable aspect of the physical space (measured space). The social-technical gap takes place in the mismatch between what the virtual space delivers to the user and what he or she expects in terms of granularity of information.

4.1.2 Spatial uncertainty

4.1.2.1 Definition

The term uncertainty refers to such dictionary words as accuracy, sureness, precise, determination and dependability. However, spatial uncertainty is an ill-defined concept, and the distinction between it and related concepts such as data quality, reliability, accuracy, and error often remaining ambiguous in the literature. For Pang (2001) spatial uncertainty is defined for both attribute values and position. It includes accuracy, statistical precision and bias in initial values, as well as in estimated predictive coefficients in statistically calibrated equations used in the analysis. In his thesis, Leonhardt (1998) adds a temporal dimension to describe a location sighting event. He uses the tuple

$$s = (t; l;p)$$

where t is the time of the sighting, l is the symbolic location of the sighting , and p is the probability that the sighting is valid. In consequence spatial uncertainty is composed of indication on the measure of distance between actual and reported location (spatical accuracy), measure of time between actual and reported sighting (temporal accuracy), and a qualitative measure of a sighting's truth (validity). Finally, Leonhardi and Rothermel (2001) take a similar approach to model spatial uncertainty At the time of the sighting the uncertainty is determined by the accuracy up of the sensor system. The uncertainty at a later time t can be estimated by the distance the mobile object may have traveled during the time $t - tl$. If a maximum bound for the velocity of the mobile object (vmax) exists, the maximum uncertainty of the location sighting can be calculated by adding the distance the object can have traveled to the uncertainty of the sensor system (Figure 19). This is described by the following equation:

$$ul\,(t) = up + vmax(t - tl\,)$$

In many cases, however, the location sighting will be more accurate than the uncertainty given by this equation, as the mobile object will not be moving at its maximum speed or not in a straight line.

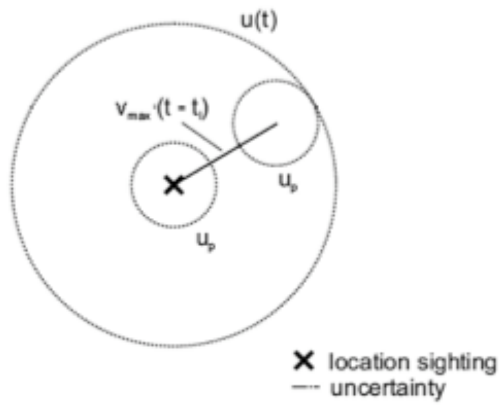

Fig. 19. Uncertainty of location information depending on the accuracy of the sensor system and the elapsed time.(Leonhardi and Rothermel, 2001)

In addition to spatial accuracy discussed above, the temporal accuracy of the location information plays a determining role in the usefulness of location-awareness. While often advertised as is, location information rarely comes in real time. First, the capture of a position comes sporadically (e.g. every 1 seconds). Second, location-aware systems rely on the network but also on update protocols used to broadcast the data (Leonhardi and Rothermel, 2001; Harle and Hopper, 2006). As a consequence, when delivered, a depiction of location-awareness is already a representation of a past situation. Moreover, such spatio-temporal information can decay and become irrelevant, misleading or even as a cognitive burden for the user. As time impacts location-awareness, a system reporting on mobile persons or objects needs to answer the combined question of "where and when" and convey the time of a location sighting. In the case of real-time systems, the schedule of the location update protocol can increase the uncertainty of the location information.

The unpredictability of many location-sensing system can create wide difference in terms of spatial quality and timeliness (Figure 20)

Fig. 20. Uneven accuracy of location-sensing technologies (a) GPS jitters in an urban environment. (b) GSM positioning zone of accuracy: Source: m-Location: presentation UK Mobile Phone Location Technology - The Current Status at the Royal Institute of Navigation Forum - Coventry in May 2004)

4.1.2.2 Sources and experiences of spatial uncertainty

Acting under uncertainty has been already widely investigated for work in dynamic conditions and uncertain environments such as nuclear power plants or air traffic control (Norros, 2004) and virtual spaces (Stankiewicz et al., 2006). However, so far, the literature in ubiquitous location-aware computing has only limited itself to describing the sources (Figure 21) and experience of spatial uncertainty (as reported in 2.1.2).

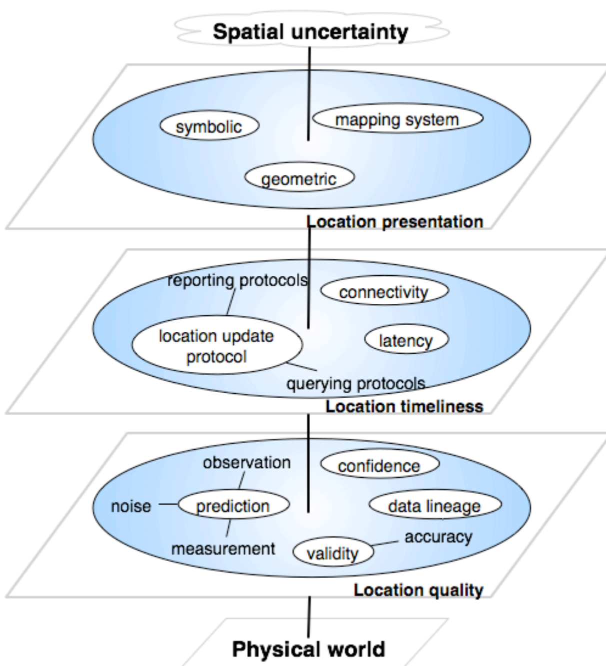

Fig. 21. Sources of spatial uncertainty (Girardin et al., 2006)

Other scholars have reported on users coping with uncertainty in a location-based game (Benford et al., 2003, Benford et al., 2005) and more in general (Satyanarayanan, 2003). That led the same authors to mention dealing with uncertainty of location (e.g. limited coverage, accuracy, variation of performance over both space and time.) and dealing with uncertainty of connection as some of the major challenges of the future of location-based experience.

Dearman et al. (2005) underline how the display of location information provided little assistance to users in interpreting the associated state of the person. The uncertainty in interpreting location information can lead to detrimental effects of location-awareness on users' understanding of the situation. In CatchBob! (Chapter 2, page 15) players spontaneously mentioned how they dealt with these uncertainties. When confronted to a discrepancy concerning their partner's position, three types of reactions had been mentioned: believing the system, saying that the system was wrong (as reported by those players from group 11: "I saw that it was indicated that B was positioned here but he was not", "I saw that B moved on the screen but I know he did not") or not understanding ("I did not get why he was there" said a skeptical participant from t group 21 with the location-awareness tool).

4.1.2.3 Approaches to reduce spatial uncertainty

Several fields related to ubicomp work on understanding and managing uncertainty: artificial intelligence (reducing uncertainty), robotics (wayfinding with uncertainty), psychology (coping/dealing with uncertainty, spatial cognition), and complexity theory (contextualizing uncertainty). They impact the design of each type of component of a location-aware system (Table 7).

Table 7. Approaches to reduce spatial uncertainty

Location-aware system component	**Approach**
Sensors	Sensor fusion Lumiere project (Horwitz et al., 1998) is based on techniques such as Bayesian modeling and inference, utility, and decision theory
Middleware	Modeling (Truong et al., 2005) Describe the confidence: D. Chalmers et al. 2004) Verification algorithm (Padovitz et al., 2004), Publish/subscribe model (Fiege et al., 2003)
Graphical interface	Reveal (seamful design, Chalmers and Galani, 2004), Predicting confusion (Loer and Harrison, 2005)

On the other hand, there is an opposite research agenda that aims at increasing the uncertainty of location information for privacy or social reasons. Spatial cloaking consists in revealing spatial coordinates with less accuracy. Similarly, temporal cloaking reducing the accuracy in time (Gruteser and Grunwald, 2003). Similarly, Gaver et al. (2003), consider that in contract with the practice in HCI, ambiguity ambiguity is a resource for design that can be used to encourage close personal engagement with systems.

4.1.3 Location information granularity

Another difficulty in interpreting location information is that the position offered or described by technology may not correspond to the positions people want to refer to when they are conversing (Rudström et al., 2005). Hightower and Borriello (2001) also raised this issue by saying that location-based technologies have the problem of turning geographical coordinates to “place” meaningful to the users. Generally, granularity can be understood as the smallest unit (or grains) of information that can be measured or distinguished respectively. Within such a grain, information differences are indiscernible. Thus, coarse granularity results in less detail. These facts have two consequences: first, the user should have access to the data quality information he or she expects.. Second, the granularity of information is an important factor for the degree of adaptation that is possible.

The granularity of the spatial information, that is to say, which scale to choose with regards to the representation of the environment is also an important issue for the design of application that support location-awareness. From their practical experience, Dix et al., (2005) mention that people and objects may have locations in and relationships to both physical space and one or more virtual spaces, and that these different spaces together interact to give an overall system behavior and user experience. Therefore, designers must take into consideration multiple space (real, measured, and virtual). A space can be in fact be made of multiple space, depending on the context (Figure 22). For instance, they describe a train that has various forms of location sensing within it. This will clearly make a 'space' of locations within the train. There are four spaces that need to be represented. First there is the outside space for instance fixed with GPS coordinates. Second there is the train space. The granularity that is required is low. Within a carriage we find a third space, which ca be represented with a Cartesian system. Finally there are seat spaces requiring fine granularity. For example, to place a paper ‘reserved’ ticket in the slot in the seat back requires millimeter accuracy. People deal remarkable well with complex spatial relationships, but it is harder for mere computers.

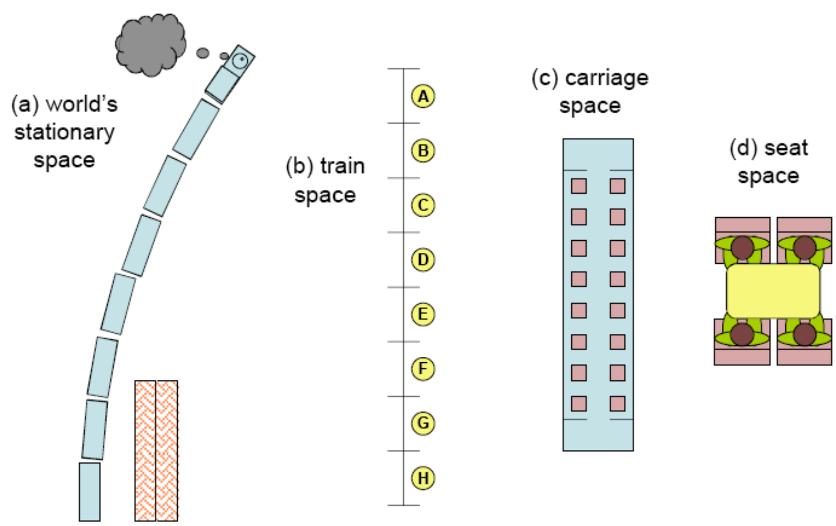

Fig. 22. Granularity taking from managing multiple spaces. (Dix et al., 2005)

That said, the existence of different levels of granularities could be worthwhile in specific contexts. For example, it can avoid privacy intrusion by allowing the adjustment of granularity depending on who requested the person's location: family can access the exact location and co-workers only at the city level. Privacy here is not just a matter of being on or off the grid but also the level of granularity one can accept to disclose to others (Smith et al. 2005; Bellavista et al., 2005). Likewise, Gruteser and Grunwald, 2003 illustrate different accuracy requirements of location-based services. They provide three typical automotive telematics scenarios: Driving Conditions Monitoring, Road Hazard Detection, and a Road Map. Services are differentiated along with position accuracy and time accuracy dimensions.

In Figure 23, we show the example of the popular web-based location-aware service Plazes[10] in the city of Geneva. The interface let users set their location automatically or manually. It shows on a based the whereabouts with its points of interest and the other user's location. However the awareness tool does convey the granularity of the location and time of this information. For instance, the airport is depicted in the river. It was probably meant to inform that there is an airport in Geneva without providing an accurate location (which would have been out of the map in that case). Similarly, the users is placed in the center of the map at the train station. However the interface fails to display the decay of the information. At the moment the screenshot was taken, the user was already long gone of the city.

[10] http://www.plazes.com/

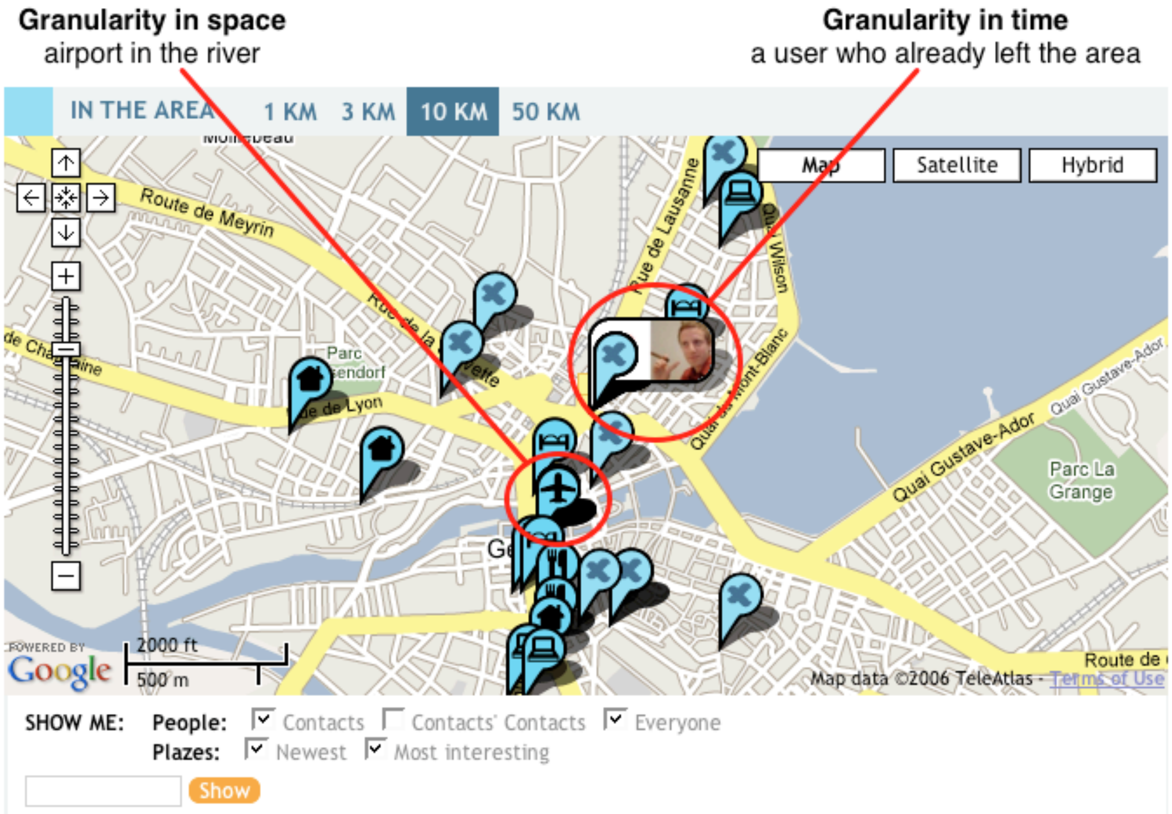

Fig. 23. Issues with the granularity of location information in Plazes

Similarly, in the field of Cartography there is the concept of generalization that takes the process of selecting and representing information adapted to a scale to make the map useful. Related to that, the domain of Human Geography touches the issues on spatial vagueness, such as the communication of vague spatial concepts (semantic vagueness) such as people's perception of the downtown of a city or the geometric of a vague region (e.g. a forest as often a fuzzy border due to a gradual transition) (Kulik, 2003).

4.2 Research perspectives

An understanding of the social–technical gap lies at the heart of CSCW's intellectual contribution. If CSCW (or HCI) merely contributes "cool toys" to the world, it will have failed its intellectual mission (Ackerman, 2000). Our understanding of the gap is driven by technological exploration through artifact creation and deployment, but HCI and CSCW systems need to have at their core a fundamental understanding of how people really work and live in groups, organizations, communities, and other forms of collective life. Otherwise, we will produce unusable systems, badly mechanizing and distorting collaboration and other social activity

While not standing in opposition to research aimed at improving accuracy and broadening availability of location aware systems, we have been exploring the relation between the granularity of location information a system can deliver in opposition to the granularity users expect. By granularity, we 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-centered (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, Flintham et al., (2003) 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, MacEachren et al., (2005) 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, Bubb-Lewis and Scerbo (1997) argue that the only way of reducing uncertainty is by exchanging information between the automatic system and the human user. In consequence, how can we design the middleware to be aware of the desired location quality and timeliness how should the interaction process between the system and user should take place?

Future work should aim at providing design solution when a location-aware system cannot match the expected granularity of information. We propose three main perspectives anchored around the concept of seamful design: (1) visualizations of spatial uncertainty, (2) design a user-centered middleware, (3) Leveraging spatio-temporal traces.

4.2.1 Seamful design

A natural solution to support the user in uncertain situation is to shift the implicit system inferences into explicit user empowerment. That is making certain contextual details and system inferences visible to users in a principled manner and providing effective means of controlling possible system actions. Bellotti and Edward (2001) propose “intelligibility” and “accountability” as two crucial features to support the user in making his own inferences.

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. 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, Chalmers and MacColl (2003) conclude that we should offer pragmatic solutions for developers delivering real world location systems for widespread use. They propose **Seamful design is a new approach to reveal and exploit inevitable technical limitations in Ubiquitous Computing technology rather than hiding them** (Figure 24a, 24b and 25). Our work exemplifies this quest for a pragmatic approach by defining and evaluating the location information granularity expected by users of location-aware systems.

However, 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. (2006) 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 Benford et al. (2006), Chalmers and Galani (2004) 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. (2005) 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, Rukzio et al. (2006) 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, MacEachren et al. (2005) 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.

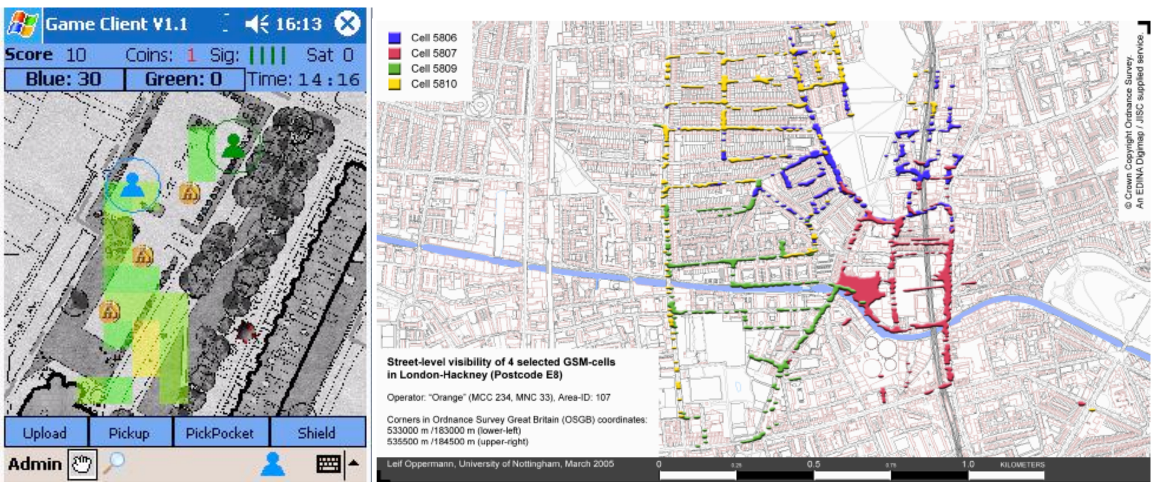

Fig. 24. Seamful design for location-based mobile games. (a) Colored squares visualizing wireless network coverage and signal strength (b) Samples of cell-ids and their GPS-positions in London (Brol and Benford, 2005)

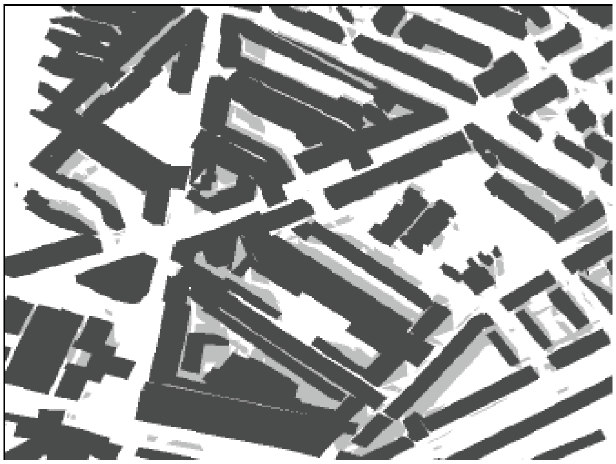

Fig. 25. In the seamful design approach (Steed, 2004) developed a visualization that shows black spots to GPS users and therefore prevent frustration caused by inaccuracy or availability

4.2.2 Spatial uncertainty visualization

For a seamful design to be successful it need to rely on a relevant visualization of the uncertainty. Uncertainty is an important issue with geospatial data sets, and hence it is not surprising to see a large number of papers from related fields such as geography and cartography. They treat uncertainty in geo-spatial data is as important as the data itself. They assess the need to focuses on how best to communicate uncertainty information accurately and effectively. The main approach is to encode uncertainty into visualization (Pang, 2001). However, we cannot yet say definitively whether decisions are better if uncertainty is visualized or suppressed, or under what conditions they are better; nor do we understand the impact of uncertainty visualization on the process of analysis or decision making. There is little agreement in the literature about the best way to represent uncertainty. A great number of these methods seem to have potential for displaying attribute certainty on static and dynamic data representations, but only a few of them have been empirically assessed and the results have not been studied in depth (MacEachren et al., 2005)

4.2.3 Designing the middleware

The inherent uncertainty and limitation of ubiquitous technologies should not only be explicitly managed on the interface, but also a middleware level. Interaction design technique may impact the implementation of middleware systems since that the management of uncertainty is still a challenge that nobody really started to tackle. For instance, a location update protocol should be aware and report on its latency issue. It could help avoid sharing information when it is too late to do anything. So far the work the work on handling granularity in a middleware level has been mainly performed in the domain of privacy. Bellavista et al., 2005 worked on guaranteeing the proper level of user privacy given the need to disclose client location information, to some extent, in order to enable LBSs. Moreover, the deliver solutions on effectively manage the exchange of positioning information (and of its variations) notwithstanding the high heterogeneity of connectivity technologies and device hardware/software capabilities. In the same domain, Fiege et al., 2003 illustrate a proxy-based architecture to provide LBSs with middleware-mediated effective access to location data, which are exposed at the proper level of granularity depending on privacy/efficiency requirements dynamically negotiated between clients and LBSs.

4.2.4 Leveraging spatio-temporal traces

In Chapter 4.2, we use the spatio-temporal to analyse people's actions in the environment (e.g. movement in space). We present them as high-levels indicators in the form of visual representations. **The analysis of the spatio-temporal characteristics of the user's current and recent movement can help improve the response to information requests**. Novel methods for mining complex geospatial objects that evolve over time and space are needed. The presentation and interaction with users of large volumes of complex geospatial data present a range of research problems. The archived information on how a location-aware system measures the physical space and how other people use it could render an image of the quality of services offered in the space.

The closest research to that come from the development a prototype device that can send a user's location over the GSM network and have accumulated large archives of spatio-temporal data for several individuals. The archive help to derive higher level information from the spatio-temporal data such as enclosing rectangles of typical movement and estimates of current transportation mode. (Mountain and Raper, 2001). The

Other (Ratti et al., 2006) approaches are base on the geographical mapping of cell phone usage at different times of the day. The results enable a graphic representation of the intensity of urban activities and their evolution through space and time. It proves to be a promising to for urban and GSM networks planning. Similar information could be used to inform the use of location-based services on the state of the infrastructure based on how other people use it (i.e. social navigation).

4.3 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 (Abowd et al., 2002). 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. Our 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 (Chalmers and Juhlin, 2005).

A first step of our research has been accomplished in using a field study to explore and analyze spatial uncertainty inherent to ubiquitous technologies (Girardin et al, 2006). Here we dealt both with individual and collaborative aspects. Currently, we are undertaking a case study on the sharing of geotagged information to identify the users behaviors when making use of location information granularity (Chapter 2.2). 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 (Chapter 2.3). This will provide individually related aspects. Based on the general lessons of these first three studies (Table 8), we plan a more comprehensive field study to evaluate the design of a city-scale location-aware system (Chapter 4.3.1). Here, we 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 (Creswell, 1997).

Table 8. Summary of the studies and their goals

Study	**Context**	**Objectives**
Field study 1 (see 2.1)	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.
Case study 1 (see 2.2)	A collaborative platform to share geotagged information.	Identify the users behaviors when making use of location information granularity.
Case study 2 (see 2.3)	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 (see 4.3.1)	Collaborative pervasive application run 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. Use of spatio-temporal data analyis software for evaluation (thicken ethnography)

Our 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 method with an innovation building approach (Järvinen, 2004). In consequence, we will execute the similar evaluation methods applied by the main contributors in the domains of ubiquitous computing and human-computer interaction (summarized in 3.1.2.4). The research process described above, that could take the form of a PhD, is summarized in Figure 26.

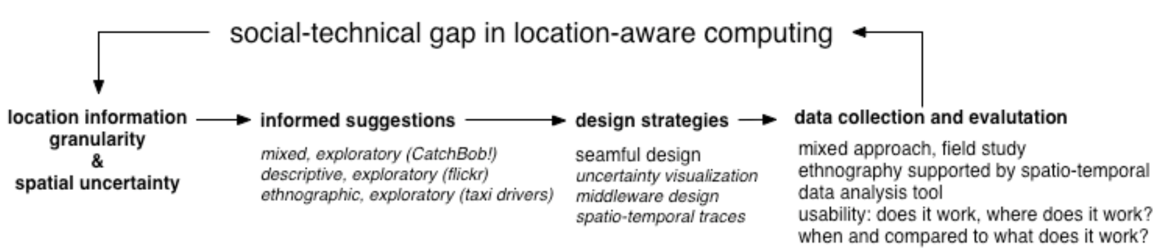

Fig. 26. Research perspectives and approach

4.3.1 Field Study 2

Any empirical study in HCI and CSCW raises methodological arguments on the balance between controlling variables and ecological validity (Kjeldskov and Stage, 2004). Pervasive technologies shed a different light on this debate. The lack of ecological validity in lab experiments becomes a serious drawback while studying applications that precisely differ from other technologies by their embeddedness in the physical (e.g. people's movement during mobility) or socio-cultural context (e.g. the role of place, as described in Harrison and Dourish, 1996). Conversely, ethnographic methods lack of generalization to articulate more abstract rules in the field of pervasive technologies. As a compromised, we plan to adopt a 'field experiment' methodology (Goodman et al., 2004) to (1) analyze the integration of location information granularity in the design of the application (2) 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).. Field experiments are quantitative experimental evaluations conducted out in the field, drawing from aspects of both qualitative field studies and lab experiments. On the one hand, they involve real users in an activity that is setup in the real world. On the other hand, we can control some variables and compare different experimental conditions. A customize spatio-temporal analysis tool will by used to "thicken" the ethnographic observations (Crabtree et al. 2006; Morrison et al., 2007)

Following standard and rigorous methods in the evaluation of both the construction and evaluation of our work should allow us to provide clear and verifiable contributions. We plan to setup an protototype to evaluate quantatitativly and qualitatively design strategies. The strategies will be informed the first 3 studies.

4.4 Delimitations and Limitations

Our research design has some limitations. Our studies confine themselves in observing user of location-aware applications in very different contexts. First, our findings based on qualitative data could be subject to other (subjective) interpretation. Second, the informed suggestion that will result might not apply to other environments. On the other hand, the results of our last field study will focus on a specific type of users (e.g. tourists in a city, students on a campus, players) and in consequence decrease the generalizability of findings.

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