Aspects of implicit and explicit human interactions with ubiquitous geographic information

Fabien Girardin

TESI DOCTORAL UPF / 2009

DIRECTOR DE LA TESI

Dr. Josep Blat (Departament de Tecnologia)

UNIVERSITAT POMPEU FABRA

Acknowledgments

This PhD thesis would not have been possible without the support and collaboration of many people.

Firstly, I would like to acknowledge my supervisor, Prof. Josep Blat, who throughout the course of this project provided me with constructive advices and timely guidance. I wholeheartedly thank him for his invaluable knowledge, and all the opportunities that made me gain academic experience.

This journey to a PhD led me to collaborate with different research laboratories besides the Interactive Technology Group (GTI). I am grateful to Prof. Carlo Ratti who hosted me in his SENSEable City Lab at the Massachusetts Institute of Technology and to Prof. Pierre Dillenbourg who gave me the confidence to reach higher when collaborating with him at CRAFT within the Swiss Federal Institute of Technology in Lausanne. I particularly owe many hours of hard work to my colleagues in these different research laboratories. Our interdisciplinary work enlarged my horizons with new skills and new languages.

My colleague and friend Nicolas Nova played a fundamental role in helping me reach my goals to the completion of this thesis through constant discussions and encouragements. A number of other people have generously let me pick their brains or commented the work reported. Thanks to Steve Benford, Barry Brown, Matthew Chalmers, Mauro Cherubini, Assaf Biderman, Julian Bleecker, Luc Girardin, Adam Greenfield, Liang Liu, Ayman Moghnieh, Toni Navarrete, Raquel Navarro, Tom Rodden, Jonathan Raper, Mirweis Sangin, Sergio Sayago, Daniel K. Schneider, Andrea Vaccari and the 7.5th Floor blog readers for the conversations about this work.

I am grateful to those who generously took time to participate in the studies reported here.

Finally, this work would not have been possible without the financial support of Barcelona Media and TENCompetence, an Integrated Project funded by the European Commission's 6th Framework Programme, priority IST/Technology Enhanced Learning. Contract 027087.

Abstract

The increasing use of mobile devices, wireless infrastructures, and the Internet is changing our daily lives, not only in the way we communicate with each other or share information but also how we relate to the environment. Through our interactions with these technologies we access and generate an informational membrane, hovering over the spaces we live in and visit. However, this information layer only imperfectly models the reality due to coarse digitization and technological limitations, challenging the human interaction. On the other hand, the presence of this user-generated ubiquitous geographic information opens novel perspectives in understanding human activities over space and time. This thesis takes on the challenge of exploring these aspects of human interactions with ubiquitous geographic information. Through qualitative and quantitative lenses, we discern the implications of the integration of ubiquitous geographic information and the resulting users strategies to cope with spatial uncertainty. Then, we exploit this contribution to explore novel approaches to infer individuals and groups time-space activities with respect to their privacy. We demonstrate the applicability of our solutions in the domains of market research and urbanism.

Resumen

El uso creciente de dispositivos móviles, infraestructuras inalámbricas e Internet está cambiando nuestra vida diaria, no solo la manera en que nos comunicamos o compartimos información, sino también cómo nos relacionamos con el entorno. A través de nuestras interacciones con estas tecnologías, accedemos y generamos una membrana de información que se cierne sobre los espacios donde vivimos y que visitamos. Sin embargo, esta capa de información sólo modela de manera imperfecta la realidad debido a una digitalización tosca y a limitaciones tecnológicas, que hacen peligrar la interacción humana. Por otro lado, la presencia de esta información geográfica ubicua generada por los usuarios abre nuevas perspectivas para la comprensión de las actividades humanas en el espacio y el tiempo. Esta tesis acepta el reto de investigar estos aspectos de las interacciones humanas con la información geográfica ubicua. Con un enfoque cualitativo y cuantitativo, discernimos las implicaciones de la integración de información geográfica ubicua y las resultantes estrategias de los usuarios para hacer frente a la incertidumbre espacial. Entonces, explotamos esta contribución para analizar enfoques novedosos con el objetivo de inferir actividades espacio-temporales de individuos y grupos respetando su privacidad. Demostramos la aplicabilidad de nuestras soluciones en los ámbitos de la investigación de mercados y el urbanismo.

Resum

L'ús creixent de dispositius mòbils, infraestructures inalàmbriques i Internet està canviant la nostra vida diària, no sols la forma de comunicar o compartir informació, sinó també com ens relacionem amb l'entorn. Mitjançant les nostres interaccions amb aquestes tecnologies, accedim a i generem una membrana d'informació qu'envolta els espais on vivim i que visitem. Aquesta capa d'informació, però, únicament modela de forma imperfecta la realitat degut a una digitalització crua i a limitacions tecnològiques, que fan perillar la interacció humana. D'altra banda, la presència d'aquesta informació geogràfica ubíqua generada pels usuaris obre noves perspectives per a la comprensió de les activitats humanes en l'espai i el temps. Aquesta tesi accepta el repte d'investigar aquests aspectes de les interaccions humanes amb la informació geogràfica ubíqua. Amb un enfoque qualitatiu i quantitatiu, discernim les implicacions de la integració d'informació geogràfica ubíqua i les resultants estratègies dels usuaris per a fer front a la incertesa espaial. Llavors, explotem aquesta contribució per a analitzar enfocaments novedosos amb l'objectiu d'inferir activitats espaials-temporals d'individus i grups respectant la seva privacitat. Demostrem l'aplicabilitat de les nostres solucions en els àmbits de la investigació de mercats i l'urbanisme.

Preface

The digitization of our lives with technologies embedded into the streets and buildings and carried by people and vehicles has appended an informational membrane, hovering over the physical space. This situation is exemplified by novel human practices that involve replying to a text message to confirm the location of a meeting, briefly working on a laptop, being lost and using Google Maps, relying on real-time traffic information to select a route, or sharing photos of a recent trip on the Web. This ubiquitous presence of information is beginning to profoundly affect the way people live and feel their environment.

These changes calls for an exploration of the implication of this recent widespread of mobile and location-sensing technologies and the geoinformation they generate and make available. The possibilities offered by them are enormous, from the new capabilities to index and communicate meaningful personal experiences, reveal urban dynamics to the suggestions of a driving itinerary in an unknown territory. However, there is still very little understanding on how human interact with this ubiquitous geographic information. This thesis starts filling this gap. It explores some important aspects of these interactions through five complementary case studies.

The articles selected for inclusion in this dissertation represent only a fraction of the publications produced for this thesis. The following is a partial list of the remaining first authored papers published.[1] They are sorted in reverse-chronological order:

Girardin, F., Vaccari, A., Gerber, A., Biderman, A., and Ratti, C. (2009). Towards estimating the presence of visitors from the aggregate mobile phone network activity they generate. In *11th International Conference on Computers in Urban Planning and Urban Management*.

[1] Available for bulk download at: http://www.girardin.org/publications/thesis/complementary_publications.zip

Girardin, F., Vaccari, A., and Ratti, C. (2008). Uncovering the presence and movements of tourist from user-generated content. In *9th International Forum on Tourism Statistics*, Paris, France.

Girardin, F., Blat, J. (2008). Assessing pervasive user-generated content to describe tourist dynamics. In *First International Workshop on Trends in Pervasive and Ubiquitous Geotechnology and Geoinformation*, Park City, USA, September 23, 2008

Girardin, F. and Blat, J. (2008). The co-evolution of taxi drivers and their in-car navigation systems. S*ituating Sat Nav session at the 2008 Association of American Geographers Annual Meeting*, April 2008.

Girardin, F. (2007). Towards reducing the social-technical gap in location-aware computing. Master of Philosophy thesis, Universitat Pompeu Fabra.

Girardin, F., Fiore, F. D., Blat, J., and Ratti, C. (2007). Understanding of tourist dynamics from explicitly disclosed location information. In *4th International Symposium on LBS and Telecartography*, Hong-Kong, China.

Girardin, F. and Blat, J. (2007). Place this photo on a map: A study of explicit disclosure of location information. Late Breaking Result at *Ubicomp 2007*.

Girardin, F. (2007). Bridging the social-technical gap in location-aware computing, Doctoral Colloquium at *Pervasive 2007*, Toronto, Canada.

Girardin, F. (2007). Bridging the social-technical gap in location-aware computing. In *CHI '07: CHI '07 extended abstracts on Human factors in computing systems*, pages 1653–1656, New York, NY, USA. ACM Press.

Girardin, F., Nova, N., Blat, J. (2006). Towards Design Strategies to Deal with Spatial Uncertainty in Location-Aware Systems, Poster at *Ubicomp 2006*, Orange County, CA. USA.

Girardin, F., Moghnieh, A., Blat, J. (2007). Towards a practitioner-centered approach to the design of elearning competence editors. *TENCompetence Open Workshop on Current research on IMS Learning Design and Lifelong Competence Development Infrastructures*, Barcelona, Spain, June 21-22, 2007.

Girardin, F., Boursinou, E., Moghnieh, A. (2007). "Convince Woody", a serious game on competence development in a distributed collaborative environment, *2nd TenCompetence Workshop on Service Oriented Approaches and Lifelong Competence Development Infrastructures*, January 11-12, 2007, Manchester, UK.

Girardin, F., Blat, J., and Nova, N. (2007). Tracing the visitor's eye: Using explicitly disclosed location information for urban analysis. *IEEE Pervasive Computing*, 6(3):55.

In parallel, from March 2003, before my PhD coursework, to April 2009 I published a personal research blog[2]. It started as an attempt to move my research notebook online to forge new connections and keep track of my thoughts. This blog has proven indispensable as a research method used to communicate my work through about 1400 posts and feedback from 400 comments. It became a research tool, part of general open science movement in which I not only regularly discussed the advances in my research domain but also shared its hesitations and failures. This transparency on the implications of my work and the ones of my peers helped me cultivate a professional persona. The informal network of researchers and professionals that belong to the readership of my blog represent an invaluable goodwill that is part of the outcome of this thesis. They encouraged me to discuss my research work in continuation of conferences and also outside of the traditional academic venues.

[2] http://liftlab.com/think/fabien

Contents

1. Introduction

> *Current technology requires information to be served from somewhere and delivered to somewhere. Heisenberg's uncertainty principle not withstanding, at geographic scales a bit always has an associated location in real geographic space. (Goodchild 1997, 383-84)*

The increasing use of mobile, digital and location-sensing technologies such as digital cameras, mobile phones, Global Positioning Systems (GPS), and web-based services in our personal and professional activities is changing our lives, not only in the way we communicate and interact with each other but also how we perceive our environment. We should add to this picture the webs of sensors, which monitor the environment, ourselves as part of this environment through our interactions with these novel infrastructures. Some of these interactions are explicit when a user knowingly operates a system to achieve a certain goal (e.g. to use of a navigation system, to georeference photos, to disclose one's location). In contrast, others are implicit when the user is not actually aware of them because he or she concentrates on more important activities (e.g. handovers on a wireless network when walking on the street, the log of the originating cellular antenna when making a phone call, driving with a navigation system in passive mode)

In consequence, the individual empowerment afforded by the ubiquitous availability of geographic information (geoinformation) is accompanied by an increased ability to create many new types of geographically referenced records that entangle the daily activities of each person into a dense web of data spread across time and space. However, there is still very little understanding on the implications of this ubiquitous presence of geographic information on people. Indeed, an extensive review of the domains of ubiquitous computing (ubicomp) and Human-Computer Interaction (HCI) shows that most of the research in those fields focuses on optimizing the accuracy of location sensing and aims at seamless interaction, prior to understanding how it could be better integrated into people's daily activities (see Girardin, 2007, for an extensive state of the art review). Some important aspects of the human interactions with ubiquitous geographic information are explored in this thesis through five case studies, which have complementary approaches to the issue (see Figure 1 for an overview).

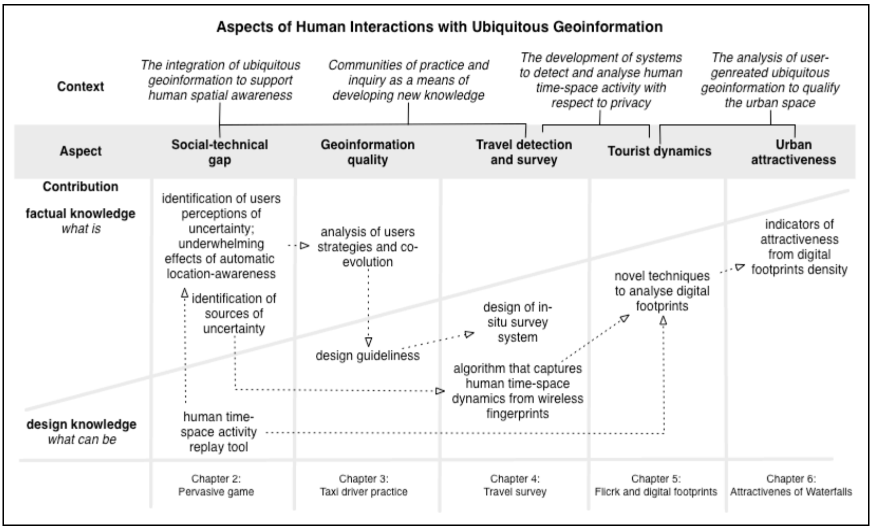

Figure 1. The articulation of this thesis through diverse case studies and their complementary contribution on human interaction with ubiquitous geoinformation,

One of the main contributions of this thesis is to provide evidences of what Bell and Dourish (2006) refer to as the “ubiquitous computing of the present”. The case studies are part of the paradigm change in the research field, in the form of proving that “ubicomp” is already here, but does not have the form that was envisioned. In consequence, we consider the imperfections of everyday life as a central theme of research in ubiquitous computing, arguing further on the warnings of Bell and Dourish: “*The seamlessly interconnected world of future scenarios is at best a misleading vision and at worst a downright dangerous one*”.

Indeed, a futurist vision of goals of the field has encouraged research into an infinitely postponed proximate future that eventually distracted the researchers’ attention from what is currently being used and its implications. Our first work, on pervasive games, was not setup against a stage of the imperfection, but this came up as an unexpected research outcome. The study proved that experimental game development could produce research insights in ubiquitous technologies research. For instance, we could explore the effects of automatic location-awareness on collaboration, the technological boundaries of location-aware systems and the users strategies to overcome the limitations and shortcomings of technologies. The publications on these insights contributed to the "*Are we there yet?*" discourse that questioned whether ubicomp was something yet to be achieved. Furthermore, this work not only helped to recognize the current impossibility of a completely seamless, invisible, ubicomp infrastructure but also suggested that users adapt to the limitations these technologies. Indeed, the presence of ubiquitous technologies on the streets (Greenfield, 2006) encouraged us in confronting real people in real everyday environments and move beyond the "fake" environments and missions of so many ubicomp studies. As suggested by Davis et al. (2005): "*developing a complex system is not a new problem. However, when looking at ubicomp systems, understanding the full complexity is often different and more difficult than in areas of more bounded scope*".

A first aspect of our results framed in a present ubicomp is the convenience of seamful interaction with location-aware devices rather than a seamless one, which is argued from the results of our case study number one (Chapter 2). Based on CatchBob!, the pervasive game we developed, we show that, despite location technologies having a degree of uncertainty, users develop intelligent strategies to cope with it. These strategies are based on understanding the way the technologies imperfectly work. A side, but important, result is that human communication on location can replace the machine sensed one, and this leads to a more immersive experience of the game (involving acts of communication carrying intentions). These findings were revealed with the development of a replay tool that visualizes the players' movements and interactions from the logged data and digital messages. However, this experimental approach limited the understanding of the real life interactions, in a wider context, with a wider range of applications, devices and artefacts, common for ubiquitous systems. Our second case study specifically analyzed this aspect.

Based on qualitative data collected from ethnographic observation, our second case study (Chapter 3) reports on the appropriation of location technology by individuals within a group of taxi drivers using satellite navigation systems and a variety of other artifacts, as we show. This work further highlights users strategies to cope with the uncertainty and different levels of location granularity of the geoinformation. For instance, the individuals with less knowledge of the environment are unable to assess the quality of the information delivered by their location-aware system. Furthermore, we reveal that the automation of the wayfinding process alters the social practices that were at the source of learning the unofficial and provisional city from the interactions with their customers. In reaction, the taxi drivers rely on an ecosystem of complementary sources of city information to support their practice. These findings support that poor geoinformation quality, lack of timeliness and completeness, and inaccuracies challenge users in their decision-making, who handle this with both frustrations and new strategies to manage these situations. These strategies are evidences that reveal the presence of a social-technical gap formed by the discrepancies between the users' expected granularity of information and what the technology can deliver. In consequence, we interpret these findings to inform the design of location-aware systems. For instance, we suggest a seamful design approach that highlights the quality of the geoinformation instead of hiding it. Furthermore, we describe the implications of automating the disclosure of geoinformation on the user experience with the immersion, learning and social impacts. At a higher level of granularity, this work embraced a broad perspective that argues against the conception of technology as an autonomous, external force imposing societal change. Our focus on everyday practices, experiences, and interpretations of geoinformation gives evidences of a co-evolution in that these location-based systems alter individual's practice and in return individuals appropriate them in unexpected ways.

The design of our third case study (Chapter 4, mobility detection algorithm for an in-situ travel survey system) fed from these understandings of a) the technological constraints that generate a fluctuating quality in the location information and b) the individuals' strategies to overcome the uncertainty. While many computer scientists and engineers consider practical constraints as detrimental to the elegance of technological solutions, we instead view them as challenges and opportunities to rethink solutions. Based on these principles and the techniques developed in our pervasive game (Chapter 2), we designed and deployed a solution that captures individual's travel experiences as they occur eliminating the recall bias of traditional survey solutions. Simple behavioural patterns, captured in this case as digital footprints, constitute a powerful unobtrusive alternative to complex technological developments of longitudinal travel surveys. This approach introduces a novel methodology of providing informative indications on human spatial dynamics from processing data sources far more reliable than traditional subjective surveys. However, detecting mobility and travel at a larger scale is difficult due to the challenge of building informative, yet unobtrusive solutions that respect privacy.

Another major contribution of this thesis takes upon that challenge. It builds on our first case study (Chapter 2, visualize logs of digital footprints) and three (Chapter 4, detect mobility from digital footprints) to explore the explicit and implicit digital footprints generated by individuals and groups to reveal their behaviours in space. Our fourth case study (Chapter 5) is a precursory analysis of the massive amounts of information that are being recorded and stored daily about people's behaviour, as they walk through the streets with their mobile phones, drive their cars and use the Web. This research went along the line of Bruno Latour who foresaw that the consequences of such information for Social Sciences will be enormous: they can finally have access to masses of data that are of the same order of magnitude as that of their older sisters, the natural sciences (Latour, 2007), adding:

I am sure that this accumulation of traces ... is worth pointing out. The precise forces that mould our subjectivities and the precise characters that furnish our imaginations are all open to inquiries by the social sciences. It is as if the inner workings of private worlds have been pried open because their inputs and outputs have become thoroughly traceable.

Geographers have a similar description of the phenomena and opportunities under the name of "new digital geographies" (Dodge et al., 2004) or "next generation Digital Earth" (Craglia et al., 2008). However, the reach of such an objective demands tools and technologies to effectively mine vast quantities of ubiquitous geoinformation (Microsoft, 2008). In the fourth case study (Chapter 5), we develop tools and analyze georeferenced information, explicitly provided by users (in fact, users' geotagged photos in

Flickr); this study was initially motivated by understanding human expression of geoinformation in the context of improving interaction. But this explicit information offered even further human traces that could be analyzed to understand human in many ways. We developed new concepts and methods for retrieving, analysing and visualising this information, which offered both geographical and temporal traces of activity. The tools were used to map tourism and non-tourism related behaviour, again going far beyond what has been traditionally coming from surveys, with an unprecedented large scale and with publicly available data. This work shows that innovative developments in spatialization, information visualization, and geovisualization are altering the nature of maps, which become tools for exploring data rather than static representations for communicating results.

This explicit and voluntary information provides a wealth of results. However, the same explicit character indicates a potential bias that motivated further exploration. Therefore, we combined and compared implicit and explicit digital footprints that visitors leave behind them in Rome, ItalyThe results show that these data sources offer probably complementary aspects, complementary human behaviours, rather than confirming through another data source the initial results, which was our initial assumption.

Nevertheless, this work showed that the analysis of these user-generated spatio-temporal data has the potential to supply high-level human behaviour information valuable to urban, travel and tourism studies. In an effort to demonstrate this potential, our fifth case study (Chapter 6) exploits these evidences as indicators of the evolution of the attractiveness of the urban space. The case study took place within a project to quantify the impact of the New York City Waterfalls exhibit on the attractiveness of the waterfront. It was made possible with the development of an interpolation model of network activity to map cellular network statistics. For that objective, we measured the relative density of digital footprints as evidences of the evolution of the attractiveness and popularity of points of interests.

In this thesis we present several aspects of implicit and explicit human interactions with ubiquitous geoinformation. Through quantitative and qualitative lenses, it discerns the implications of the integration of location-aware technologies in the framework of their human use and appropriation. It provides answers on the strategies to cope with spatial uncertainty and how this automation of geoinformation delivery alters the social dynamics, the learning process of the environment and the human engagement with it. We also explore the massive amount of ubiquitous geoinformation generated through people's explicit and implicit interactions with mobile devices and wireless infrastructures. In this context we develop new concepts, tools and techniques to extract the individuals and groups spatial dynamics, while respecting users' privacy. As a result, we show the applicability of these methods in the domain of market research and urbanism. This thesis dissertation presents these contributions through a compilation of the following articles:

Chapter 2: First case study on "The generation and user perception of uncertainty in ubiquitous geoinformation".

Girardin, F., Blackstock, M., Dillenbourg, P., Finke, M., Jeffrey, P., Nova, N. (2007). Issues from Deploying a Pervasive Game on Multiple Sites, In *Common Models and Patterns for Pervasive Computing Workshop*, 5th International Conference on Pervasive Computing, May 13, Toronto, Ontario, Canada.

Girardin, F. and Nova, N. (2006). Getting real with ubiquitous computing: the impact of discrepancies on collaboration. *e-Minds International Journal on Human-Computer Interaction*, 1(1):60–64.

Chapter 3: Second case study on "The appropriation of ubiquitous geoinformation"

Girardin, F. and Blat, J. (In press). The co-evolution of taxi drivers and their in-car navigation systems. *Pervasive and Mobile Computing Journal*

Chapter 4: Third case study on "The implicit interactions with wireless infrastructures as source of travel detection and survey".

Girardin, F., Nova, N., and Dillenbourg, P. (Submitted to the *Journal of Location-Based Services*). Detecting air travel to survey passengers on a worldwide scale.

Chapter 5: Fourth case study on "User-generated ubiquitous geoinformation as evidences of tourist dynamics"

Girardin, F., Dal Fiore, F, Ratti, C., and Blat, J. (2008). Leveraging explicitly disclosed location information to understand tourist dynamics: A case study. *Journal of Location-Based Services* 2(1), 41–54.

Girardin, F., Calabrese, F., Dal Fiore, F. , Ratti, C., and Blat, J. (2008). Digital footprinting: Uncovering tourists with user-generated content. *IEEE Pervasive Computing*, 7(4):36–43.

Chapter 6: Fifth case study on "Digital footprints as evidences of urban attractiveness"

Girardin, F., Vaccari, A., Gerber, A., Biderman, A., and Ratti, C. (2009). Quantifying urban attractiveness from the distribution and density of digital footprints. *International Journal of Spatial Data Infrastructure Research*, 4.

A full list of papers presented before the thesis submission can be found at http://www.girardin.org/fabien/publications/thesis/

2. The generation and user perception of uncertainty in ubiquitous geoinformation

In this chapter, we report these valuable lessons from experiments based on a pervasive game called CatchBob!. This game was primarily developed as an artefact to explore social and cognitive implications of geolocalisation (see Nova (2007) for extended findings in that context). However, the availability of the CatchBob! platform also led us to investigate other issues, more related to the user experience of ubiquitous geoinformation and the inherent design issues of such platforms (for a discussion of the wide range of aspects, see Nova and Girardin, 2009). In the scope of this thesis, we particularly investigate the different roles played by the technological infrastructure (e.g. wireless access points, web servers, network modules on the mobile devices) as source of uncertainty in ubiquitous geoinformation perceived by the players. Indeed, building ubiquitous applications that exploit location requires integrating underlying infrastructure for linking sensors with high-level representation of the measured space to produce a pleasant user experience. However, the real-world constraints limit the efficiency of location technologies. An inherent spatial uncertainty embedded in mobile and location systems creates a social-technical gap that constantly challenges the coexistence of digital and physical spaces. In the context of CatchBob!, we were able to highlight that the quality of the ubiquitous geoinformation influences the user experience and the infrastructures must be consciously attended, as they are unevenly distributed, unevenly available.

This chapter includes papers that discuss the sources of spatial uncertainty, the perception of uncertainty and contextualize these findings within this research work in ubiquitous computing:

Girardin, F., Blackstock, M., Dillenbourg, P., Finke, M., Jeffrey, P., Nova, N. (2007). Issues from Deploying a Pervasive Game on Multiple Sites, *Common Models and Patterns for Pervasive Computing Workshop, 5th International Conference on Pervasive Computing*, May 13, Toronto, Ontario, Canada.

Girardin, F. and Nova, N. (2006). Getting real with ubiquitous computing: the impact of discrepancies on collaboration. *e-Minds International Journal on Human-Computer Interaction*, **1**(1):60–64.

However, as these papers have been published at the early stage of this thesis, they do not report on some valuable elements with regard to the user experience of ubiquitous geoinformation. We believe it is particularly worthy describing more in depth the research method as well as the contributions on the underwhelming effect of automatic location awareness and the ability to replay the players path.

2.1. Methods and participants

Players were recruited in teams of three, which led to a total of 30 teams and 90 players. The games were set up so that no teams played at the same time. The participants were all between 19 and 28 with a mean age of 23.1. More male than female players signed up, so teams were generally made up of two males and one female. Most were students from different disciplines (biology, mechanical engineering, computer sciences, architecture). Participants spoke either French or English but they used the same language within a group.

Each game lasted one hour and participants went through four steps. The first one consisted in receiving the game instruction by the experimenter at the lab. Participants were asked to find the virtual object and surround it with one constraint in mind: they should take the shortest path to it. We also let them try a demo of a TabletPC software; users could then try the annotation feature and ask questions about the software interface. The second phase was devoted to planning: groups were given five minutes to plan their strategy on a paper map, which was then left in the office. The third phase was the game itself. The experimenter led the group of three players to the common starting point at the centre of the campus. They had 30 minutes to complete the game, which – from the pretests we ran – was sufficient to achieve the goal without much time pressure. Finally, the last phase was a post-game interview that we recorded. After the game, players were debriefed with a replay of their activity.

2.2. Data collection and analysis

Data on the players' activity was collected via system logging and semi-structured interviews. Data logging captured all movements in space as well as players' communication through map annotations (content, moment of exchange). This logging allowed us to uncover the spatial strategies and review the discussion that led to their implementation. They were also compared to the discussion in the planning phase that we also recorded. The post-game semi-structured interviews were meant to elicit the players strategies, the implementation of the decided strategy (and how they reshaped it) and all the problems they had during the game.

The questions further probed the participants' experience with the application (communication and location-awareness feature); what elements of the environment they relied on to play the game; and how they experienced the game setting (activity, exploration of space, coordination tactics). A replay tool displayed in real time the position of each group member, as well as their annotations. Those traces of the activity were presented to help players in giving an account of what happened, an interview technique known as self-confrontation.

2.3. Replay tool

The "Replay tool" allowed us to confront the players to a replay of their path after the game, as well as the actions they performed (Figure 1). With all the players' explicit (e.g. annotations, refresh of others' positions,) and implicit interactions (e.g. positions, connection loss) logged on each game mobile devices and server, the tool provided a richer appreciation of the recorded data with a fast overview of the recorded events. Other similar systems have been developed to support both log and media analysis through the synchronised presentation of media and information visualisation style data exploration tools. A number of visualisation tools are provided for the visual exploration of log data, allowing an analyst to summarise all statistical data from a trial, or focus on a particular factor of interest (see Morisson et al., 2006). This type of tool shows potential to help social scientists analyzing data from field studies involving user interactions with ubiquitous technologies. However, the use of a "Replay tool" also relies on technical knowledge such as the formats of system events and technological issues of the ubiquitous infrastructures. It typically requires one of the tool developers to be present during replay and analysis. This experience was at the source of the development of the algorithm that detects air travels from the mobile devices interactions with spotty wireless infrastructures, as presented in our third case study (Chapter 4).

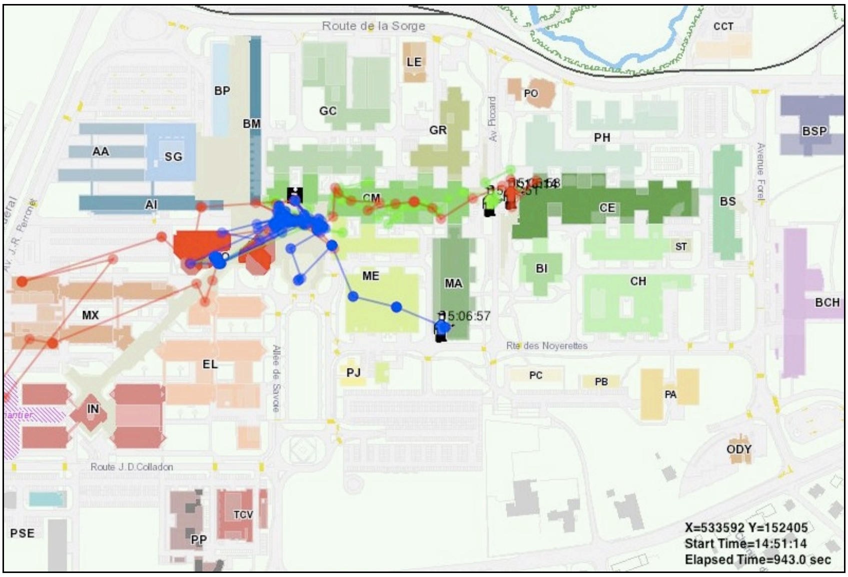

Figure 2. Screenshot of the Replay tool that displays the path of the three players from their positions.

2.4. Underwhelming effect of automatic location-awareness

The papers presented in this paper describe how the combination of both logging and interview data helped to give us a rich picture of how the spatial environment of the game was not uniform and homogeneous. However, as reported in Nova et al. (2006) another elements of the effect of automatic disclosure of location information (i.e. location-awareness) is worth reporting.

We tested CatchBob! using two interface configurations: in one case, we provided players with a mutual location-awareness interface (MLA), in the other case, without mutual location-awareness (NoMLA). MLA participants could see their own location as well as their partners' whereabouts updated in real-time on the interface. NoMLA participants could only see the update of their own location. These two experimental setting conditions allowed us to test the influence of location-awareness on collaboration. This field experiments illustrate that the following:

- An underwhelming effect of mutual location-awareness on players' mutual representations: participants in the NoMLA groups better recalled their partner's movement in space than participants in the MLA groups. The main reason is that participants in the NoMLA groups compensate for the lack of information about others' location in space by sending map annotations. Since self-reported location information was only sent when it made sense to the participants, it seemed that the players more effectively internalized them (see Nova, 2007 for a complete description).

- An underwhelming effect of mutual location-awareness on players' communication: the location-awareness feature not only lowered the exchange of messages about location (which is logical), it also diminished communication about strategy and direction issues.

- Players in the "NoMLA" groups took better advantage of the annotation capabilities, using annotation to express their location, their path and their strategy. The players with the awareness tool were able to annotate as well but did not use this capability.

As a consequence, we found that automating the location-awareness of participants made them more passive. Indeed automating MLA is different than sending one's position in space. This fact raises an important issue regarding communication and spatial information: compared to automatic positioning in which location is just information, self-declared positioning is both a information and an act of communication. If A tells B where he or she is located, not only does B know A's location but he or she also knows that A considers that it is useful for B to know it. This is important for players in order to better coordinate themselves on the field.

2.5. Summary of the contributions

In summary, this case study contributes to these issues with:

- Guidelines from the lessons learned from the deployment of a collaborative pervasive game on two different sites. We emphasize on the practical aspects of getting a pervasive system deployed without any extra special infrastructure;

- Users of ubiquitous technologies often react to spatial uncertainty due to systems' limitations;

- Categories of reactions to spatial uncertainty;

- Design of a tool to replay players path from their logged interactions with the wireless infrastructure;

- Automating location-awareness can be detrimental to group collaboration.

Issues from Deploying and Maintaining a Pervasive Game on Multiple Sites

Fabien Girardin[1], Michael Blackstock[2], Pierre Dillenbourg[3], Matt Finke[2], Phillip Jeffrey[2], Nicolas Nova[3]

[1] Pompeu Fabra University, Passeig de Circumval·ació, 8, 08003 Barcelona, Spain
Fabien.Girardin@upf.edu
[2] Department of Computer Science, University of British Columbia, 201-2366 Main Mall, Vancouver, Canada
michael@cs.ubc.ca
[3] Swiss Federal Institute of Technology Lausanne, CE 1 530 1015 Lausanne, Switzerland
{Pierre.Dillenbourg, Nicolas.Nova}@epfl.ch

Abstract. In this paper we present the lessons learned from the deployment of a collaborative pervasive game on two different sites. We emphasize on the practical aspects of getting a pervasive systems deployed without any extra special infrastructure. Based on our experience, we describe the issues providers and administrators must take into consideration to deploy and maintain pervasive environments. In this perspective, we highlight that ubiquitous technologies must be consciously attended, as they are unevenly distributed, unevenly available.

Keywords: ubiquitous computing, field study, seamful design.

1. Introduction

In the recent years, the research based on pervasive gaming have demonstrated principles and lessons that can be applied more generally in systems for mobile work in vast work settings [5]. Several studies reveal the diverse ways in which players experience the limitations of positioning and network technologies [3] and how to take advantage of the `seams' and heterogeneity inherent to pervasive systems [2]. Another investigation [4] discusses sketchy and slow mobile Internet access, variations in the quality of speech transmission, loss of connections or ambiguities in positioning as an everyday reality for mobile users.

These studies suggest that designers must understand how to meet the user needs taking in to consideration the limitations and availability of network connectivity and sensor data. However, the literature provides only sparse descriptions of the deployment and maintenance issues of providing pervasive games over multiple sites. In this paper, we describe CatchBob!, the pervasive game platform we designed and used on both the university campus of the Swiss Federal Institute of Technology Lausanne in Switzerland and the University of British Columbia in Vancouver, Canada. Then we present the main issues we experienced in deploying and maintaining the system. Finally, we conclude with open questions on the integration of the limitations of technologies as parts of large-scale ubiquitous environments.

2. The Platform: CatchBob!

CatchBob is a pervasive game running on Tablet PCs in which groups of 3 teammates have to collaboratively find an object on a university campus [7]. Completing the game requires the players to surround Bob with a triangle formed by each participant's position in the real space. When the players are close to the "Bob", the triangle they have to form appears on the display; they then have to adjust it in the proper way. The only mean of communication the players have is by annotating the map display on their mobile device with a stylus. The original game took place on the Swiss Federal Institute of Technology Lausanne campus, whose dimensions are a 850x510 meters field mixing both indoors and outdoors [Figure 1]. The second deployment of the game took place outdoors on a large part of the university campus, in an area approximately one kilometer square played outdoors.

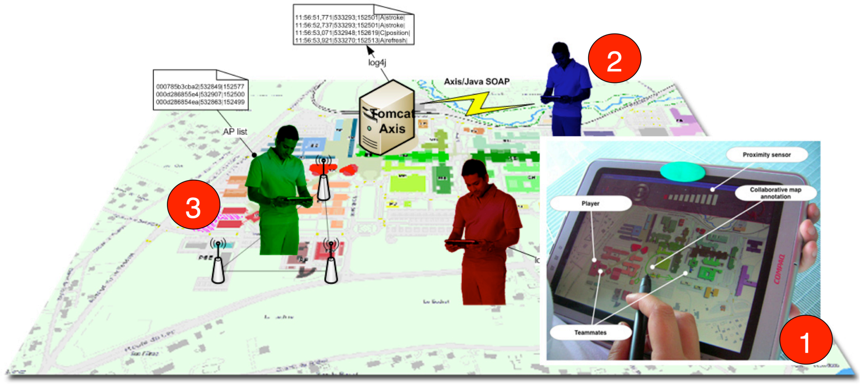

Figure 1: The CatchBob! architecture: (1) Players use TabletPCs to view their and the other players' position. They communicate by annotating the map with a stylus. (2) The data are synchronized over the campus 802.11 network using the SOAP protocol. (3) The positioning algorithm runs on each mobile 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.

3. Issues from the Real World

Based on our experience of deploying and running CatchBob! in both locations (50 games played in Lausanne, 6 in Vancouver) over different periods, we have been able to identify a set of recurrent issues described in the following subsections.

3.1. Wireless Networks are neither Open nor Pervasive, nor Stable

During the development of the platform, the Lausanne campus network security policies drastically changed in forcing the unique use of the TCP (Transmission Control Protocol) port dedicated to HTTP (Hypertext Transfer Protocol) communications. In consequence, we developed our high-level remote access protocol upon SOAP (Simple Object Access Protocol). In fact, the versatility SOAP facilitated the iterative process of rapid prototyping and user-centered design required for the development of pervasive software in research since we did not need to concern ourselves with lower level protocol and data marshalling issues.

The WiFi network topologies in 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.

Finally, the transfer of packets to and from access points can show significant asymmetry, and high packet loss can occur despite apparent network access. The latency inherent to wireless networks disturbed some players who questioned if all the messages were actually broadcasted to their teammates.

3.2. 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. The mobile clients self-determine their position using the Place Lab [6] native libraries and a simple centroid algorithm. This approach performs a positioning accuracy of 10-40 meters, which consistently decreases when the user is in areas of low network connectivity. It proved to be a viable strategy for the scale of our game as we could take advantage of the approximately 300 WiFi access points deployed on the campus. In Vancouver, while the number of access points is much higher (approximately 3000) due to the predominance of the outdoor settings of the campus, and the extensive changes to the UBC wireless network over the testing period we integrated GPS functionalities. While this improved the accuracy of the positioning, wireless network connectivity was mainly available indoors. This limited the outdoor playground to the areas near buildings with line of sight to satellites.

While many researches aim at improving accuracy and broadening availability of positioning system, our experience suggest that designers might first think of what location information granularity is expected by users of a location-aware system. We are conducting further investigations to understand the level of information accuracy a location-aware system must provide to support its users in certain activities.

3.3. 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 used in Vancouver, 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. In that context, we concur with [1] in their general observation that infrastructures are inherently messy; uneven in their operation and their availability.

3.4 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].

4. Conclusion and Open Questions

Many infrastructures assume an even quality of sensor data and reliable infrastructure. From our experiences of deploying and maintaining a large scale collaborative pervasive game we've found neither is true. Indeed, we suggest that the network and systems issues we present 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. In consequence, we would like to raise the following high-level questions:

- 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 compensate for varying quality, or as part of the application?
- How can a general purpose platform for ubiquitous applications make use of the seams in infrastructure - is this something that needs to be done on a case by case basis?

References

1. Bell, G. and Dourish, P. In press. Yesterday's Tomorrows: Notes on Ubiquitous Computing's Dominant Vision. Personal and Ubiquitous Computing.

2. Bell, M., Chalmers, M., Barkhuus, L., Hall, M., Sherwood, S., Tennent, P., Brown, B., Rowland, D., and Benford, S. Interweaving mobile games with everyday life. In CHI (2006), pp. 417–426.

3. Benford, S., Crabtree, A., Flintham, M., Drozd, A., Anastasi, R., Paxton, M., Tandavanitj, N., Adams, M., and Row-Farr, J. Can you see me now? ACM Trans. Comput.-Hum. Interact. 13, 1 (2006), 100–133.

4. Broll, G., and Benford, S. Seamful design for location-based mobile games. In Lecture Notes in Computer Science (September 2005), vol. 3711, pp. 155–166.

5. Chalmers, M., and Juhlin, O. New uses for mobile pervasive games - lessons learned for cscw systems to support collaboration in vast work sites. In Paper presented at the workshop "Computer Games & CSCW" at ECSCW'05. (2005).

6. LaMarca, A., Chawathe, Y., Consolvo, S., Hightower, J., Smith, I. E., Scott, J., Sohn, T., Howard, J., Hughes, J., Potter, F., Tabert, J., Powledge, P., Borriello, G., and Schilit, B. N. Place lab: Device positioning using radio beacons in the wild. In Pervasive (2005), H.-W. Gellersen, R. Want, and A. Schmidt, Eds., Lecture Notes in Computer Science, Springer, pp. 116–133.

7. Nova, N., Girardin, F., and Dillenbourg, P. ’Location is not enough! ’: an empirical study of location-awareness in mobile collaboration. In WMTE (2005), pp. 21–28.

Getting real with ubiquitous computing: the impact of discrepancies on collaboration

Fabien Girardin[1], Nicolas Nova[2]

[1]Interactive Technology Group, Department of Technologies, University of Pompeu Fabra, 08003 Barcelona, Spain
Fabien.Girardin@upf.edu

[2]Center for Research and Support of Training and its Technologies, School of Computer and Communication Sciences, Swiss Federal Institute of Technology Lausanne (EPFL), 1015 Lausanne, Switzerland
Nicolas.Nova@epfl.ch

Abstract. Ubiquitous computing is still a maturing field of investigation. The vision of the seamless integration of computers to people's life has yet to happen, if it ever has to become a reality. Nowadays, most mobile, distributed systems and sensor technologies have their faults and limitations. Users of ubiquitous technologies often learn to avoid or rectify the systems failures. However, there is still a lack of quantitative information concerning how they impact the collaboration. Therefore, we propose to use a 'field of experiment' approach based on a pervasive game platform. Our aim is to rely on a mix of qualitative and quantitative evaluations to find out how uncertainties modified the collaborative processes.

1. Introduction

Nowadays, a considerable amount of development is taking place in ubiquitous computing and a growing number of research labs are investigating this field. They work in the various research topics that form ubiquitous computing, including distributed computing, mobile computing, sensor networks, human-computer interaction, and artificial intelligence. The father of ubiquitous computing, Mark Weiser [1], defined it as forcing the computer to live out here in the world with people. Currently, the field is still not as mature as Weiser envisioned.

Ubiquitous environments must deal with unreliable network, latency, bandwidth, security, unstable topology, and network homogeneity. The most ubiquitous device, the mobile phone, has its faults. Lack of coverage, broken conversations, bad roaming, empty batteries, the limitations are plentiful and must be dealt with on a daily basis. Many times we learn strategies to adapt to avoid of rectify the systems failures. We are still a far reach of the strict definition of ubiquitous "existing or being everywhere at the same time: omnipresent".

In our case, we are interested in studying the impacts of technological limitations and users manipulations by terms of collaborative interactions. The platform we use to meet this end is the emerging field of ubiquitous computing games, which offers an interesting platform to study the aforementioned phenomenon. This approach is also the one described by [2] and [3].

In this paper, we first introduce the current studies in that field. Then we explain the pervasive game we developed and the outcomes of the first experiment we conducted. We conclude by describing our method of mixing collaborative and quantitative data to study the role uncertainty plays in collaborative ubiquitous systems.

2. Dealing with myths of ubiquitous computing

Previous user-centered studies have been done to understand how to design applications based on the lack of maturity, the underlying imperfections and inherent uncertainties of ubiquitous technologies. The most common methodology to do so is the use of ethnography and hence the collection of qualitative data about people's behavior towards technology and collaboration.

Benford et al [4] reveal some of the complexities involved in designing collaborative location-based experiences. Based on qualitative data from the location-based educational game called Savannah, they describe the frustration when users are unable to establish a shared context and act together due to system limitations. Moreover mismatches between the designer's conceptual model and user's mental, inherent to ubiquitous technologies application design, lead to serious confusions among the players. They leave open design questions on how users avoid and rectify the difficulty of the system (e.g. when connectivity is temporarily lost, when the GPS unit loses line of sight or in case of poor latency between the mobile devices and the server).

Likewise, Antifakos et al. [5] argue that perfect and reliable context information is hard if not impossible to obtain. They evaluated a feedback mechanism that displays the uncertainty inherent in the context information. Their study shows that human performance in a memory task is increased by explicitly displaying uncertainty information. However they claim that further studies must be performed on "the tradeoff between the cognitive load, which displaying uncertainty information causes, and the added value that it provides.

Finally, Chalmers et al [6] go a step further through the argumentation of seamful rather than seamless design to reveal the physical nature of the ubiquitous systems in, for example, the uncertainty in sensing and ambiguity in representations. Conversely, they emphasize that seamful design as just one potential way to “design for appropriation” and to support the more widespread acceptance of ubiquitous computing technologies.

3. CatchBob!

Our approach targets the use of a game to study how people deal with uncertainty. In line with this goal, we developed a pervasive game called CatchBob! as an experimental platform for running psychological experiments. Catchbob! has been designed to elicit collaborative behavior of people working together on a mobile activity. In the game, groups of 3 teammates have to find a virtual object on our campus at EPFL in Lausanne. 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 1.

Figure 1. CatchBob! interface as used by a player

In addition, the tool also enables communication: 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) are 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.

4. Previous experiment

The results of our previous study on location awareness [7] show that it is better to let users control and express their location the way they want as opposed to have it automated. Giving them the possibility to embed location cues with other kind of information like map annotations appeared to be a good solution to support collaborative processes like communication or strategy discussions. By extension, it is now fair to question the importance of positioning accuracy as well as the quality of the coverage and connectivity of ubiquitous system.

During post-game interviews, we also discovered mental model mismatches on how the players perceived the system would work and their actual experience. In talking about their experience of the game in general, some players said "I did not move physically, but I moved on the map" other "The proximity to Bob changed even though I did not move". Some players came with a pre-conception on the quality of indoor positioning systems. One stopped playing, because of the latency in the synchronization of the annotations. We now want to find out if the players overcome and adapt to the technological limitations or whether it impacted their overall performance in the game.

5. Conclusion

The approach deployed here is called 'field experiment' approach [8] which means that we want to take the advantage of both ethnographical studies (ecological validity, use of qualitative data) and controlled experiments (controlled factors, use of quantitative data). As we did to study the use of location-awareness tool [7], we plan to rely on a mix of qualitative and quantitative evaluations to find out how uncertainties modified the collaborative processes. First and foremost, qualitative data are interesting with regards to describe the kind of situations where people face discrepancies as well as the solutions they use to overcome the systems' limits. Then quantitative indexes would allow us to get some concrete measure of how uncertainties impact the task performance or collaborative processes. Among the quantitative index we have, there is the uncertainty of location which is represented by the amount of time when no position were given to the player, the positioning accuracy described by the number of scanned access points. The uncertainty of connection, the number of seconds and frequency the user has been disconnected, is also of interest since it might be detrimental to both the task performance and communication among the group. This will allow us, for instance, to check the correlation between these variables and the frequency/quality of communication, the players' spatial behavior or the time they spent to complete the game. Eventually, we believe that the articulation of both kinds of data is relevant to make sense of users' behavior.

References

1. Weiser, M.: The world is not a desktop. Interactions. (1994) 7-8.
2. Barkhuus, L., Chalmers, M., Tennent, P., Hall, M., Bell, M., Sherwood, S., Brown, B.: Picking Pockets on the Lawn: The Development of Tactics and Strategies in a Mobile Game. Ubicomp 2005: Tokyo, Japan (2005) 358-374
3. Benford, S., Crabtree, A., Flintham, M., Drozd, A., Anastasi, R., Paxton, M., Tandavanitj, N., Adams, M., Row-Farr, J.: Can You See Me Now? Transactions of CHI Dec 2005, In Press
4. Benford, S., Rowland, D., Flintham, M., Drozd, A., Hull, R., Reid, J., Morrison, J., and Facer, K. 2005. Life on the edge: supporting collaboration in location-based experiences. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (Portland, Oregon, USA, April 02 - 07, 2005). CHI '05. ACM Press, New York, NY (2005) 721-730
5. Antifakos, S., Schwaninger, A., Schiele, S.: Evaluating the Effects of Displaying Uncertainty in Context-Aware Applications. In Ubicomp'04, 6th International Conference on Ubiquitous Computing, Nottingham, September 2004
6. Chalmers, M., Bell, M., Brown, B., Hall, M., Sherwood, S, Tennent, P.: Gaming on the Edge: Using Seams in Pervasive Games. Pervasive 2005 workshop on Pervasive Games (PerGames 2005)
7. Nova, N., Girardin, F. & Dillenbourg, P.: 'Location is not enough!': an Empirical Study of Location-Awareness in Mobile Collaboration Full paper for IEEE International Workshop on Wireless and Mobile Technologies in Education, Tokushima, Japan.
8. Goodman, J., Brewster, D., Gray, P.: Using Field Experiments to Evaluate Mobile Guides. In Schmidt-Belz, B. and Cheverst, K., (eds.), Proceedings of HCI in Mobile Guides, workshop at Mobile HCI 2004, Glasgow, UK, Sep 2004.

3. The appropriation of ubiquitous geoinformation

Our previous case study showed that ubiquitous geoinformation brings an abstract representation of the physical environment, different from the spatial representation of the user. In addition, a fluctuant quality of the data impairs this information layer. These issues, within the widely distributed element of contemporary information technologies, do not connect with the seamless vision of "technology" becoming invisible and disappearing from our consciousness. In this case study, we exploit the market success of in-car navigation system (satnav) that creates the opportunity to learn from a real-world interaction with location-aware systems in conjunction and their geoinformation. Using an ethnographically-informed study with a community of early adopters, the taxi drivers in Barcelona, we explore questions related to the evolution of the practice of driving and navigating. The findings show that:

- The navigation system completes an arrangement of artefacts providing layers of geoinformation to support the job. There are real-time information sources such as the satnav system, dispatched radio, electronic booking system, mobile phone and radio. In contrast, other artefacts provide asynchronous information to keep the knowledge of events and activities in the city up to the day (e.g. newspaper, scribbled list of "unofficial" points of interest and the street and map directory of Barcelona.
- The wayfinding practice takes place in phases. There is a "to go" phase in which the driver takes the proper direction and the "to arrive" phase that necessitates different geoinformation at a different granularity drop off location (the number of the street, a monument, a corner). There is a consensus that a satnav is an unbeatable tool when it comes to reaching a specific destination in a village and leaving it and it is a strong reason for purchase. The reason to purchase is to feel more serene in appropriately performing the job rather than being more productive.
- The integration of location-aware technologies has not created a distinct sphere of practice despite the access to a

digital representation of a physical space, but the knowledge acquisition evolves with people using systems in ways unanticipated.

Based on these finding, we identify design strategies to address significant issues in the mobile work environment, such as promoting the driver's serenity as a design goal, or the need to develop methods to manage and communicate the quality of the geoinformation (seamful design). We also highlight areas where social interactions are relevant and connected them with learning the city and its environments.

These design implications echo very well with our first case study (Chapter 2), in the context of a pervasive game where players have different reactions towards uncertainty and the automatic disclosure of location information has an underwhelming effect on the immersion of the players with the game. These findings contract the notion that with location-aware system "we will never be lost or be more immersed in the physical world".

We report this work in the paper:

Girardin, F. and Blat, J. (In press). The co-evolution of taxi drivers and their in-car navigation systems. *Pervasive and Mobile Computing Journal*.

The co-evolution of taxi drivers and their in-car navigation systems

Fabien Girardin[1,2], Josep Blat[1]

[1]Universitat Pompeu Fabra, Interactive Technologies Group
Roc Boronat 138, 08018 Barcelona, Spain
{fabien.girardin,josep.blat}@upf.edu
[2]Barcelona Media
Diagonal 177, 08018 Barcelona, Spain

Abstract. The recent market success of in-car navigation systems creates the opportunity to investigate the appropriation of location-aware systems outside laboratory settings. Through ethnographical lenses, we study how this technology changed the practice of a massive community of its early adopters, the taxi drivers of Barcelona (Spain) and, specifically, their exploitation of pervasive geoinformation. The results show co-evolution: taxi drivers adapt to their in-car navigation systems and adapt them to their needs; in particular, there are evidences of an alteration of the learning processes and of technology appropriation to reduce stress rather than to improve efficiency. We argue that these findings can inform the design of next-generation location-based services.

Keywords: Satellite navigation systems, human-computer interaction, co-evolution, qualitative field study

1. Introduction

The recent popularization of in-car navigation systems (Satnav) is due to the maturity of Global Navigation Satellite Systems (GNSS), to the improvements in hardware (e.g. in processing power, screen size and resolution), and to advances in the collection and visualization of geographic information (e.g. in-vehicle sensors, navigable map databases). The resulting devices meet a need of drivers to enhance the safety, comfort and efficiency of their travel. In Japan, where the technology has been available for more than ten years [1], millions of vehicles have got systems installed. Confirming the projections made 10 years earlier [2], a recent market research study stated that one in six (17%) U.S. adults currently own or use a GPS location device or service, and 33% of them use it in their vehicle [3]. This is the first massive adoption of a location-aware system[3], which, however, comes along with poor integration of the technology into the driving practice. For instance, as early as in the late nineties, five years after its introduction, the Japanese transport ministry already identified accidents caused by drivers distracted by their route guidance systems and by problems due to inaccurate mapping information or ambiguous directions. The latter limitations have been widely experienced[4]: only 15% of the participants in a survey thought that the routing instructions generated by their navigation systems were always completely reliable [4].

Some studies have dealt with reducing the problems from a technical issues point of view (see [5] for a review of the challenges), or enhancing the delivery of location and navigation information [6], or a more appropriate visualization [7] within the constraints of mobile devices [8]. These technological and usability investigations reveal discrepancies between the technical implementation and the social requirements of location aware computing. Ackerman [9] labels such problems as a 'social-technical gap'; a divide between what must be socially supported and what can be technically supported. Specific examples of gaps in the use of location-aware applications are experiences of information uncertainty, of interaction ambiguities, of confusion on the user's intention, or of frustration due to time lost. These gaps pose new design challenges in location-aware computing that are hard to solve. Parts of a dreamt up perfect system must be ignored to provide a working solution with new opportunities for user's engagement with the environment; this trade-off originates a lot of the tension between "technically working" and "organizationally workable" systems in any given implementation [9]. In fact, interface designers will increasingly have to wrestle with this tension to match the capabilities of sensors and the shifting applications requirements [10].

---

[3] We term "location-awareness system" a system that provides facilities for orientation and localization

[4] A survey of 7380 members of the British Automobile Association (AA) revealed that 30% of respondents said that their satnav had taken them to places they did not want to go, while 44% disagreed with this statement.

However, the imperfections in terms of bugs and glitches are notorious and yet largely accepted too as a routine part of the ‘conveniences’ of computers [11]. Users massively buy Satnav devices in spite of their failings. In fact, it seems that drivers develop a new ‘Satnav literacy’ to respond to a certain 'spatial anxiety' when finding their way through an unfamiliar environment [12]. More precisely, as argued through this paper, Satnav users adapt to their systems and adapt their systems to their needs. This co-evolution has been theorized and argued in several HCI contexts [13, 14, 9], and might be traced in the past, as, for instance, in the Mercator map projection, which simplified navigation calculations, whose introduction was an act of tool adoption and user creation [15].

Our study, based on qualitative observations and interpretations of a field study, shows aspects of how the co-evolution of drivers and in-car navigation systems takes place: the intertwined adaptation of Satnav systems and driver’s practice is mainly structured as a transformed ecosystem of artifacts, while drivers use Satnav in unpredicted ways to reduce their anxiety and learn their workspace, the city and its environments; and their use might lead to a potential reduction of the social interactions in the car.

From this observation and understanding of actual use and co-evolution of people interaction with location-aware technologies, and keeping the needed delicate balance with predicting how novel technologies support a real human need, we discuss how the results can be valuable to designers of next generation systems. For instance, exploiting intelligent use to fit better users’ needs, if the system is capable of only partial satisfaction. In our study, we describe how users of navigation systems assess the quality of the geoinformation, as we believe there is valuable design knowledge to be learnt from the appropriation of imperfect technologies and how the technologies evolve with users’ practices.

After introducing the context of our ethnographic work, we discuss research related to the appropriation of mobile and positioning technologies, and its implications. Then we present our methodology, describe and analyze our observations, comparing them with closely related work and finally draw some implications for the design of future location-aware systems. We conclude with considerations on the results within the research on co-evolution mechanisms.

2. Context

Empirical evidences of co-evolution/adaptation of systems to needs and of users' practice to systems are difficult to collect because of the challenge to properly observe subjects in real life situations. As the use of computers in taxis has been common in some countries for a few years [16] the study of taxi drivers is relevant. In the second half of 2007, we took the opportunity of the market success of Satnav systems to observe how positioning technologies integrate into the existing practice and how this practice affects the technology use. Our aim is to provide evidences of the importance of the context and the situations in the use of the systems. We analyzed the co-evolution in three different aspects:

1. Acquisition: why and how this new technology gets integrated with other artifacts and how, over time, it modifies their use;
2. Expectation gap: why the integration into the practice does not match the initial expectations;
3. Evolution of the appropriation: despite the gaps, how the practice evolves in relation a) to the awareness of, and reactions to, the limitations and imperfections of the system; b) to the driver's knowledge of the environment; c) to the access to geoinformation both from the system and other artifacts.

The collection of contextual evidences through ethnographic techniques was carried out within a community of taxi drivers in Barcelona, Spain, with 10,400 licensed cars. This community forms a massive population of early adopters of in-car navigation systems that also rely on more traditional elements, such as mobile phones and paper maps, to support their work. The study of this community is very relevant because it provides evidences of location-based systems impact and implications, outside the laboratories. We believe that this approach is necessary to inform the design process with considerations on the evolution of the appropriation of the technology.

3. Method

Our research approach is based on ethnographic methods often used in ubiquitous computing [17, 18]. Other scholars have dealt with the use of navigation systems, but mainly relying on quantitative data collected from surveys [19], sensor data [20] or experimental settings [21]. These approaches do not fully appreciate the scope and implications of the practice evolution when using novel technology. We were inspired by Chrisman [22], who argues that the study of technology removed from its construction or its use neglects the active role users play in the co-evolution process. Our design intended to provide an interpretation of user practices and situated activities, but without imposing our previous understanding onto the situation. We did not mean to be exhaustive; we focused on how taxi drivers use the systems, but did not examine how the systems work (e.g. interfaces, mobile antennas, software and hardware).

We collected empirical evidences from 12 taxi drivers (11 males, 1 female, respecting the male/female ratio within the community) with a working experience ranging from 6 months to 20 years (2 with less than one year; 3, 4 and 3 between one and five, five and ten, and ten and twenty respectively). They owned their navigation system for at least 6 months. We stopped collecting data when no significant new information or evidences emerged with additional subjects: after 10 taxi drivers our categories, described later, were already filled with data to the point of saturation [23]. Of course, more empirical data could provide further emerging ideas outside the scope and questions of this research.

We conducted semi-structured interviews in Spanish (we translated some excerpts for this paper) at the Barcelona airport parking lot for taxis (Figure 1). It provided a good setting to get in touch with taxi drivers, because they often must wait there for over 30 minutes, spending their time chatting, playing (e.g. chess, scrabble, golf), cleaning their cars, drinking refreshments and eating. The interview covered the three different aspects of the co-evolution indicated earlier with questions on the reasons and expectations for the acquisition, the particular evolution of use (e.g. how the practice was before and after its use), the context of use with successes, failures and the acquisition of the knowledge on the city. It is well known that informants are often selective in what they describe and discuss, and we needed to go beyond the interviews: we collected additional insights from observation of driver work settings (e.g. artifacts used and their evolution, context of use in the wayfinding process) and behaviors (e.g. engagement with different types of geoinformation such as streets, numbers, instructions, points of interest) while driving. Acting as customers, we requested rides from and to a railway station, a major hotel and an address at one of the many very narrow streets in the Gracia neighborhood in Barcelona. Each informant took part in one session, lasting from 45 minutes to 1 hour, divided in two halves, the first collecting insights in the parking lot, which triggered a semi-structured interview; followed by a ride.

Figure 1. Waiting area at the Barcelona airport. Usual activities include fixing or cleaning the taxi, sleeping, reading, eating and playing.

We collected rich data consisting of photos of work settings (e.g., to record the ecosystem of artifacts discussed later), videos of taxi rides (e.g., to capture key moments of access to geoinformation) and written field notes from the interviews. After each session we analyzed and compacted the data. Our analysis consisted in a careful reading of the different materials and in highlighting parts that were related to the aspects of the co-evolution we wanted to focus on. We organized the relevant parts into common themes, and coded the documents using the emerging themes.

The findings have been extracted within a framework for observation of the co-evolution that focuses first on the contextual ingredients that support their practice, then how this context evolves during the navigation and its situated activities, and finally, how it impacts their knowledge of the city and in return how the knowledge impacts on the use of the navigation systems. We summarize the findings extracted around these themes in the following section.

4. Findings

Satnav systems relieve car drivers of the need to closely observe the environment, to look out for road signs or landmarks, to orient themselves with respect to where they are located, or to memorize a chosen route for future reference. In this section we see how this takes place in the practice of the taxi driver community.

4.1. The Satnav system as complementing and modifying an ecosystem of artifacts

The artifact model has been used in the ethnographically inspired Contextual Design methodology [24], abstractly representing the physical objects supporting work, along with their usage, purpose and information content. We started with the model as an observation framework, and we enhanced it to a discovered ecosystem of artifacts that we discuss in terms of the types of tools, how their respective use relates to each other, and when and why drivers access their geoinformation.

The navigation system completes an array of artifacts providing layers of geoinformation to support the job (Figure 2). Based on our observations, we categorize some as detecting real-time information sources such as the Satnav system, dispatched radio, electronic booking system, mobile phone and radio. Another category provides less dynamic information of the city: newspapers supplying daily events and activities; scribbled list of “unofficial” points of interest requested by customers (e.g., strip clubs), and above all the street and map directory of Barcelona *Guia Urbana de Barcelona* (*Guia*), generally kept at easy reach, on the seat near the driver’s, above the dashboard or in the interior storage compartment. The purpose and context of use of these artifacts are described in more detail in Table 1.

Artifact	**Purpose**	**Context and situation of use**
Satellite navigation system	Inform on the whereabouts; provide directions to destination	At the start of the ride to locate the neighborhood and/or in proximity to

	(e.g. street number, hotel, place); keep track of speed radars.	destination to precisely locate a street number[5]
Guia Urbana de Barcelona, the street and map directory of Barcelona which is a thick and dense book with all the streets and points of interest	Locate the destination, find references, and locate points of interest and hotels.	At the start of the ride to locate the neighborhood and/or in proximity to destination to precisely locate a street number
Dispatched radio	Receive jobs from the call center.	When looking for customers and when navigating to accept future rides. In rare situations when the driver gets lost to get advice; for professional questions (e.g. asking on special rates for some destinations); in the rare cases of emergency (attempt robbery).
Electronic booking system	Receive jobs from the call center	When looking for customers and when navigating to accept future rides.
Mobile phone	The mobile phone often available is seen as a social link to family and friends, and is very rarely used as a tool to support their work. One driver told me that he used it a few times to check if a table was available at a restaurant for clients (particularly foreigners). This is a service given as added value, but he "normally should not do it".	Used for social contacts with friends and relatives and also for administrative duties (e.g. calling the bank). Mainly used during breaks and waiting period or in the rare situations when the driver gets lost and there is not a source of information within the car that can help. Drivers express a level of respect for their passengers in their behavior: trying to make few or no calls on

[5] Satellite navigation systems have two main modes. In the passive mode the system mainly provides a sense of orientation and situation awareness. The active navigation system is started by a destination being entered, and the system may provide routing advice, turn by turn guidance and traffic information.

		their mobile phones
Newspaper	Provide updated information on the city	During breaks
FM Radio	Provide entertainment and updated information on the city (e.g. news, debates)	Depending on the driver, the radio can be used with some respect towards a passenger by keeping the radio volume low
Handwritten notes	Store information on informal destinations of the city that are not present in the *Guia* and in the navigation system	To keep track of specific destinations and opening hours. On customer request

Table 1. The eco-system of artifacts that taxi drivers use for navigation, social interactions and to update their knowledge.

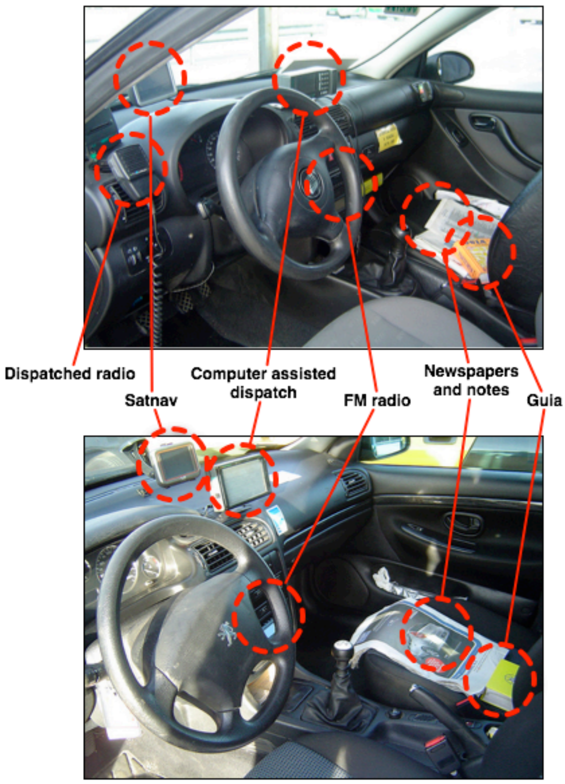

Figure 2. The ecosystem of artifacts for navigation and updating knowledge: Dispatched radio, computer-assisted dispatch, FM radio, satellite navigation system, newspaper, paper notes and the Guia. Mobile phones are kept in the pocket, in the compartments or with a specific hand-free car kit.

In the ecosystem of artifacts, Satnav systems are preferred to the *Guia*, even by the most experienced drivers who have memorized most of the city knowledge and very rarely make use of the *Guia*. Nowadays, they prefer to interact with their Satnav and open the *Guia* only as fallback (e.g. when the system does not contain a street number or lacks information). Even after 20 years of experience, one informant still perceived retrieving information from the *Guia* as a demanding task. Compared to it, "hitting the screen of the Tom-Tom is a pure pleasure". As they only rely on the system when driving to unfamiliar destinations, which after 20 years only happens rarely, they keep it the glove compartment, and used it as an occasional "lifesaver".

The following subsections provide more detail on the (evolving) use of the ecosystem of artifacts.

4.2. The ecosystem and the modified strategies of wayfinding

The use of the wayfinding artifacts is different during two main stages. As prior to the appearance of Satnav systems, drivers first take the appropriate overall direction during a "to go" phase while the later "to arrive" phase requires more precise geoinformation to drop off the customer (i.e. the location of a street number, a monument, or an intersection of two streets). When aiming to unknown destinations, drivers access the geoinformation as in a "funnel". First, the goal is to quickly retrieve the area of the destination (usually through the Guia, but if it does not provide suitable information such as reference points in the area, the drivers engage with the navigation system); and decide direction based on this broad information. It is only when approaching the destination area, that the exact address in the navigation system is entered – or alternatively, found through a thorough look at the Guia, when in slow traffic or stopped by a red light. The more precise route is chosen in this phase. The selection of 3wayfinding artifact depends on the speed to access the information (e.g., a long street name is difficult to be entered in a Satnav) and on the experience of the driver with the geoinformation quality provided (e.g. wrong street numbers in some areas). Informant B explained that he engages with the system only during the second phase to avoid misleading routing information in the first one (Figure 3), as a taxi driver takes alternative routes depending on the time of the day and circumstances (e.g. traffic, weather conditions, passenger preferences). The specific implementation of this “two phase” seemingly general strategy is thus modified by the introduction of the Satnav.

Figure 3. Use of the "Guia" at a stop when approaching to destination

A major problem for a taxi driver is to be lost after dropping off a customer in an unfamiliar area. Therefore, on the way to the destination taxi drivers gather information to get back into known territory and are either very cautious in the path taken to enter the area (”*I am a very good observer*” said informant A) or use their Satnav when going back downtown Barcelona. They observe landmarks (e.g. a tall building), 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). Then a Satnav comes in handy. Informant B mentioned that in these situations he entered “Plaza Espana”, a large roundabout in the center of Barcelona. Other access their Satnav bookmarks of saved destinations such as “home” or “Barcelona center”.

4.3. A modified learning process

These strategies of geoinformation access during navigation modify the learning process of taxi drivers to master the city, knowledge important to their practice. In the past, the driver would open the Guia and browse the index of streets and points of interest to access a map of the destination area, which was a way to learn the city by doing. Another important one is from the customers themselves, as they communicate tricks and insights not available through official books and commercial systems. We have discussed that experienced drivers prefer Satnav systems to the Guia; for the younger generations, the integration of the Satnav modifies the old learning process with three salient issues: the need to assess the quality of the geoinformation, the ability to temporarily disengage from the environment, and the amputation of some social interactions, which we discuss next.

4.3.1. Learning the quality of geoinformation

The less experienced taxi drivers express mixed feelings about the quality of service of their Satnav: ”It is like my cell phone, sometimes it does not work well”, and the correctness of the information “it is a potential problem”. The latter reveals that, they did not expect system inaccuracy at acquisition. As the Guia is difficult even for the more experienced drivers, the less experienced ones deeply rely on their Satnav, and they have to learn when not to rely on them, which becomes part of their “Satnav literacy”. For instance, informant J could name the places where he found the navigation information to be absolutely irrelevant (e.g., access to major squares). When in doubt on the reliability of his Satnav, he would use the Guia, which is “more accurate and complete”, and remains the better source of information to learn the city particularly as it provides a detailed index of streets, points of interest and city-related information.

4.3.2. Easier learning and more relaxed engagement with the environment

The Satnav used in the passive mode described earlier is turned sometimes into a learning tool as it tells the street names or the presence of speed radars while driving – which is an easier learning, demanding less attention, than learning from the Guia. This mode enables a more relaxed driving: in the past, drivers would count the number of streets to cross (that they knew by heart) before making a turn; when the passive mode is on, the driver can pay less attention to the environment for a while, knowing that a proper position will be provided when needed, even though this functionality was not expected when acquiring the device.

4.3.3. Social amputation

A more social learning alternative is to draw on customer's knowledge. The drivers often elicit wayfinding information and learn navigation tricks known to locals by proposing alternatives routes for the customer to choose. This decreases the driver's responsibility to value and assess directions and helps to avoid complaints. However, the Satnav presence might reduce the opportunities for this learning process to take place: route directions provided by the system give less room to argumentations and discussions between drivers and customers, changing the social configuration. The discussions move to other topics (the state of the traffic, what is being discussed on the radio) or are replaced by silence.

The Satnav presence modifies the social interactions with remote friends and colleagues as well. Informant E was relieved that he did not have to use his radio to ask colleagues about particular location information. And drivers ask less for directions to locals (e.g. in remote villages) or to other knowledgeable people (e.g. to truck drivers at red lights in industrial areas)..

4.4. Serenity over efficiency; companionship

Taxi drivers purchased Satnav systems to 'reduce their spatial anxiety'. They might face moments of uncertainty during a ride in a village or an unfamiliar area, such as one of the many suburban business areas rapidly grown in recent years. There is a consensus that a Satnav is currently unbeatable when it comes to reaching (and/or leaving) a specific destination in a village, and this is a strong purchasing reason. But taxi drivers' goal is to feel more confident during their job rather than to be more productive. Informant B describes the Satnav as a tool to be calm rather than to make more money, or to improve efficiency, in his words "*I can go everywhere and relax*", while informant Y said "*the fear of getting lost with a customer I felt in my stomach now disappeared*". Other drivers mention that it calms both them and their customers: ”*with it they know I cannot cheat them*”, “*it reassures them that I go to the proper destination*”. This is an example that efficiency is not always the main goal of the integration of technology at work, as considered usually.

The feeling of relying on a “companion” in critical situations is revealed as well when informants refer to the Satnav as a “he” (and their car as a “she”). This does not prevent that the most experienced keep it in the glove compartment most of the time and retrieve it only when necessary. This “companion” might be a false friend of the less experienced when it provides inaccurate information, as discussed earlier. This could lead them to a vicious circle: to rely on the technology to learn the city and thereby reduce their interactions and social sources of learning, and when they get uncertain on the quality, they are cut from the social sources to solve it. Let us remark that we have shown some taxi drivers escaping this vicious circle by using the *Guia*.

Figure 4 presents the findings within the framework allowing co-evolution observation: from the acquisition reasons through the gaps with respect to expectations to the co-evolution itself. First we focus on placing the satnav in the context of location-aware “systems” that support practice and the overall goals, through the gaps discovered with respect to expectations, to reveal how this context evolves, and how the city knowledge and learning strategies are modified. The specific findings related to the taxi-drivers work practice will surely evolve beyond what we have described, but we believe the framework, the focus on learning, on motivation, on studying the ecosystem of artifacts, on the analysis of the work strategies evolution to be more generally useful for an ethnographical approach to HCI. We discuss this further below.

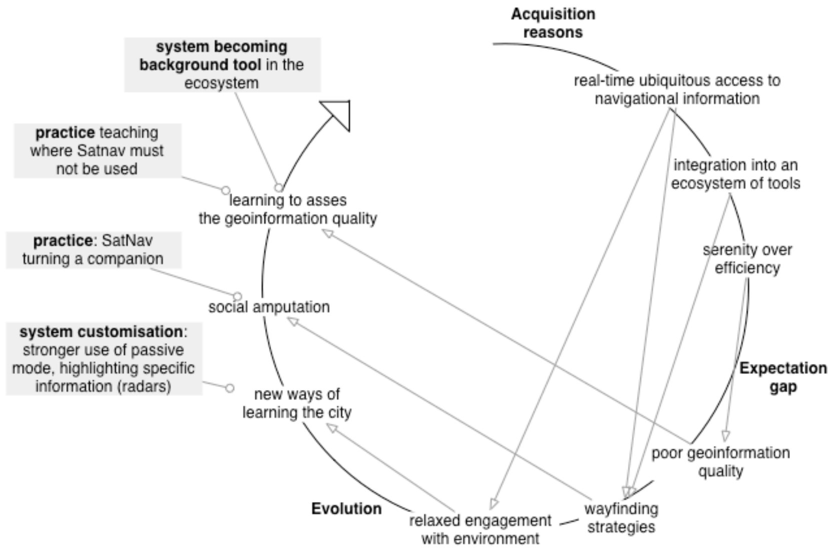

Figure 4. The findings within the observation framework of co-evolution aspects from acquisition, through expectation gap, into the evolving appropriation

5. Discussion

Some researchers have looked at the integration of new mobile technologies into the mobile workers's practices, aiming at understanding the role of technology and artifacts at this work and identifying opportunities to develop appropriate solutions to support workers [25] and understand the socio-technical aspects of their work [26, 27].

5.1. Beyond usability

In-vehicle navigation system usage and driving behavior patterns studies [4] show that systems are frequently set in active mode when users travel in unfamiliar environments, but use them less in familiar ones, when they can benefit from local knowledge, as in our findings. Their focus is usability issues; our additional consideration of experience and context of use, allows us to relate this usage with wayfinding and learning strategies. We go beyond focusing on the device, and we share [28] interest in the contextual practice with mobile and location-aware devices, in the losses and opportunities, taking a full-circle perspective [22].

Elaluf-Calderwood & Sørensen [29] conducted a longitudinal ethnographic study of London driver behavior with empirical data provided by qualitative interviews to discover relationships between the drivers' practices and the supporting mobile technology. Corroborating our findings, they point out that the most interesting technological opportunities may be thwarted by practical barriers such as problems of supporting individual taxi work with Satnav devices. The devices designers seem to assume the driver gives control entirely away and simply follows directions - when these are far from perfect. This creates problems in job allocation, billing and payments when systems lack positioning accuracy in dense urban areas or do not take into account physical obstacles to compute a distance. While their study focused on dispatching taxi drivers and looking for customers, we did it on wayfinding practices that include social interactions, which allows us to deal with the evolution of city learning strategies

Leshed et al. [30] focused on people's everyday practices, interpretations of and experiences with their Satnav, analyzed the complexity of changes created by the technology introduction with an understanding of losses and opportunities, specifically discussing the implications of the drivers' relationship with their systems on their engagement with the environment. As we do, they argue that the full understanding of issues of the (dis)engagement with the environment needs perspectives that go beyond usability issues. Their results on observations of 10 North-American drivers are echoed in our findings, despite the different cultures, for instance, that the active presence of a navigation system alters the social interaction. We have seen the Satnav relevance related to the car as a social place for learning; they more generally suggest the car as a place of conversations. Both works support the need to reveal the geoinformation ambiguity as a design feature. As we observed the job as based on the environment knowledge, we improved the understanding via an "ecosystem of artifacts model", supporting (the evolution of) the geoinformation access. It allowed us to identify better users' strategies to appropriate the technologies and the context of use, leading us to reveal a modification of the learning process and the importance of the geoinformation granularity during (the different phases of) a ride.

5.2. Deskilling?

Field studies on navigation systems have shown evidences that their introduction had de-skilling effects on orientation and navigation [31] and spatial knowledge [32], the latter stating that "*The more the driver relies on the system to locate jobs, the less he or she relies on their in-depth knowledge of where they need to position themselves to maximise income*". Leshed et al. [30] show a few instances of social de-skilling. We have shown social amputation signs in experienced taxi drivers, but location de-skilling deserves further discussion. While informant F, an experienced driver, thought that "*the newcomers who use a navigation system do not gain knowledge of the city, because they follow the recommendations and stop thinking*", our analysis of the less experienced does not reveal negative affects on their acquisition of geo-knowledge skills: they are eager to learn the city and master the imperfections of their Satnav systems to perform better their job. Drivers learned using traditional sources such as the *Guia* and the newspapers. Now they also use the Satnav in passive mode to learn in familiar areas (e.g., keeping track of the street names and their sequence) as well as to detach themselves from the orientation process. Less experienced drivers must access multiple sources of information from an ecosystem of artifacts, slightly breaking the myth that Satnav system change a "skilled" job unto an unskilled one, whereby anyone with a GPS could do the taxi driver job. Our observations suggest that the Satnav loses over time its usefulness to support navigation to the point of finishing in the glove compartment most of the time.

Our study reveals the appearance of new skills such as assess the geoinformation quality with respect to navigation and orientation. Indeed a Satnav provides only a reduced, disembodied understanding of the environment [33], and the fluctuating quality of the geoinformation is a source of uncertainty [34], as in many other location-aware systems. We observed the reliance on an ecosystem of artifacts to patch complementary limited information. Our informants learned not to rely completely on their Satnav when they could not assess the information quality. Besides learning to interpret the system and its inaccuracies, they open their *Guia*. Informant G claimed that when a conflict emerged between his Satnav and his intuition he started to "improvise" and he would either switch it off or ignore it for a while. The location and opportunity determined the action, as theorized by Suchman in her situated action theory [35]: "*Idiosyncrasy, improvisation and knowledge are all useful tools when choices between planned and situation acts are complex*". In our case, the understanding of the limitations and imperfections of the technology is part of the knowledge.

However, the presence of the technology altered the social practices that were at the source of learning the "unofficial" city from the knowledgeable customers. This may trigger new social sources and practices to capture this kind of information. At this stage we have no evidences of this, but it is clear that the Satnav does not provide it.

5.3. Design implications

Our ethnographical based findings can contribute to the design of navigation systems. But instead of formulating a requirements list, our aim is to open the design space rather than limiting it [18]. We aim at informing design at a high-level through considerations of human perception and socio-cultural issues, rather than following the classical engineering design, focused on competitors benchmarking and system integration, on providing usability guidelines and feature-centered recommendations; which has been adopted by the GPS technology development so far (Svahn [19]).

Let us note that our design suggestions are inspired by observations within a specific community – more and different opportunities might emerge in different cultural contexts and work settings.

5.3.1. Designing for trust and dependability

The current central goal of Satnav is to support driving safety and travel efficiency, for example by identifying best routes. Efficiency - the main goal of the integration of technology at work – is sometimes translated into poor design through strong and silent automation [36]. Promoting the driver's peace of mind is not seen a design goal. Our field study shows that the comfort of trusting a "lifesaver" is a prime motivation for purchase; fitting with trust being an important factor of new technology adoption as key component of human-automation interaction [37]. As they do not know whether their navigation system is always reliable, some taxi drivers might riskily transfer their trust to artifacts of their in-car ecosystem. Trust poses even more issues in terms of design for dependability with the future integration of real-time information from navigation systems that act as sensors[6] or cellular probes [38] and of map corrections with the participation of volunteers[7] and customers[8]. Instead of offering the most efficient indications based on hidden algorithms and real-time information, we suggest that the system should provide reasons to trust the information (e.g. others have navigated successfully in this neighborhood, the presence of this radar has been validated today), and that it even surrenders to other resources when some real-time information cannot be trusted, unlike the current approach to normalize fuzzy, incomplete GIS data and present navigation assistance as trustworthy information [39].

5.3.2. Highlighting the quality of geoinfomation

Elaluf-Calderwood and Sorensen [29] point out "*even the most interesting technological opportunity may be thwarted by minor practical barriers. Include discussion of problems with support of individual taxi work (not coordination) through GPS systems when these assume the driver relinquish control entirely and simply follow directions when these are far from perfect*". In their study, this uncertainty was the main reason taxi drivers felt discouraged to try new location-aware technology. Positioning data are fairly accurate, but they could be embedded in poor information due to erroneous or outdated GIS data, and, as we mentioned, a lot of drivers think they received inaccurate device instructions [4]. Our study shows that poor geoinformation quality, its lack of timeliness and completeness or inaccuracies challenge drivers' decision-making, who experience frustrations but develop new strategies to manage these situations. A design approach supporting this development is the seamful provision of enough knowledge to support drivers' assessment of geoinformation quality [40]. Rukzio *et al.* [41] have shown that the display of uncertainty by navigation devices improves solutions in spite of unreliable and incomplete

[6] Dash: http://www.dash.net/
[7] Open-Street Maps: http://www.openstreetmap.org/
[8] TomTom Map Share: http://www.tomtom.com/page/mapshare

data. The system could reveal some information quality (has it generated problems before?) and timeliness (when was the map last updated?). Additionally it could take into consideration that different levels of granularity are needed in different navigation phases to display the uncertainty only when the appropriate granularity is not available.

5.3.3. Supporting social interaction and learning

We have shown instances of social de-skilling, not necessarily, rather than navigational or orientational. Since Satnav systems are designed to interact with the driver, they decrease the opportunities for customers to engage socially with drivers, needed in the city learning process. One could think of systems pretending to acknowledge the presence of passengers and taking advantage of ambiguity or the detection of new elements in the environment to elicit interactions. For instance, the system could reveal the geoinformation uncertainty as a ground for interpretation and argumentation [42]. Reveal rather than hide error-prone or outdated information could reduce the driver's over-reliance on the system, but also raise the passenger's participation in the navigation in "normal" circumstances (of course, not in "lifesaving" situations!).

Svahn [19] points out that navigation services primarily address traveling in unfamiliar driving environments, while most driving takes place in familiar areas, concluding that a wider range of navigation services tailored for different contexts is needed. We did find evidence of different use in those different areas, and the learning process of unfamiliar areas could be improved with the disclosure of difficult aspects by highlighting the names of narrow streets.

6. Conclusions and future work

We explored aspects related to the evolution of the practice of driving and navigating and how drivers feel, learn the physical environment (the city) and engage socially within a change of technology, and we report evidences of co-evolution, i.e., drivers adapt practices to their new systems and adapt their use to their needs. To be able to do this, we needed a perspective broader than previous Satnav studies typically focused in usability issues based on experimental approaches inside labs; and moved beyond the concept of technology as an autonomous, external force imposing societal change. We are interested in people's everyday practices, experiences, and interpretations with their Satnav, and we developed an ethnographically informed study, through observations and interviews of taxi drivers. We have extended the ethnographical technique "artifacts model" to an "artifacts ecosystem model" analyzed through a grid that allows to identify better users' strategies. Our framework to analyze real use co-evolution might be used in other contexts, and through it we identified new strategies addressing significant issues in the mobile work environment, such as promoting the driver's peace of mind as a design goal, or new ways to manage and communicate the geoinformation quality by satnav systems. We identified areas where social interaction is relevant and connected them with city and surroundings learning, and uncertainties sharing; and suggested losses and opportunities that might arise.

At a higher level, we showed that the integration of location-aware technologies has not created a different sphere of practice despite the access to a digital representation of a physical space (as argued by Dourish [43]), but that the knowledge acquisition evolves by people using systems in ways unanticipated by the designers, and by adapting resources to their needs in new ways, e.g. creating handwritten notes to complete the limitation of official information provided by a navigation system and a street directory; or keeping the navigation system in passive mode to learn the urban environment. Thus, system designers should assume that people will try to tailor their use [44] by placing them within a modified ecosystem of tools and their interrelated use, in which part of the knowledge might not be digitally represented.

Our study emerged from 12 taxi drivers using Satnav in Spain, and further work could overcome their related limitations, extending findings and exploring other questions, for instance by comparing the practice of those who remain without Satnav with those who have adopted them, or focusing on the practice when drivers are on their own, without customer, or developing a larger more longitudinal study. Cameras and post-hoc discussions could be additional observation strategies, possibly augmented by an underlying logging of activities to fuel post-hoc discussion.

Questions on the integration and appropriation of next generation navigation systems integrating real-time mobility information similar to those of this paper should be posed again [45], for instance, whether in practice this leads to taxi driving becoming an unskilled job as indicated by Elaluf-Calderwood and Sorensen [29], or the appropriation of real-time urban data is a deskilling or stress reducing factor or whether their lack of geographical relevance [46] keeps triggering the co-evolution of process of taxi-drivers and their navigation systems. Or posed with respect to the integration of mobile phone-based navigation services that incorporate various modes of transportation [47]. A rather unexplored research question is how new technologies can improve the services provided by taxi drivers to passengers.

Acknowledgements

We thank the taxi drivers for their time and availability. Also, we are indebted to many people for their generous feedback and stimulating discussions. In particular, thanks to S. Sayago, A. Moghnieh and the participants of the Situating Satnav session at the AAG 2008.

References

[1] S. Azuma, K. Nishida, and S. Hori, "The future of in-vehicle navigation systems," in Vehicle Navigation and Information Systems Conference, pp. 537–542, 1994.

[2] R. Heft, "The navigation market for road vehicles," in IEEE Position Location and Navigation Symposium, pp. 109–114, 1998.

[3] Harris Interactive, National Study Shows GPS Adoption Rates Relatively Low, but Offers Recommendations to Accelerate Market Penetration. http://www.harrisinteractive.com/NEWS/allnewsbydate.asp?NewsID=1241, 2007.

[4] N. Forbes, "Online survey of in-vehicle navigation system users." http://www.mrl.nott.ac.uk/ nlf/, 2006.

[5] S. Benford, "Future location-based experiences," tech. rep., JISC Technology and Standards Watch, 2005.

[6] G. Look, B. Kottahachchi, R. Laddaga, and H. Shrobe, "A location representation for generating descriptive walking directions," in IUI '05: Proceedings of the 10th international conference on Intelligent

user interfaces, (New York, NY, USA), pp. 122–129, ACM Press, 2005.

[7] R. Suomela and J. Lehikoinen, "Taxonomy for visualizing location-based information.," Virtual Reality, vol. 8, no. 2, pp. 71–82, 2004.

[8] M. Rohs and G. Essl, "Which one is better? : information navigation techniques for spatially aware handheld displays," in ICMI (F. K. H. Quek, J. Yang, D. W. Massaro, A. A. Alwan, and T. J. Hazen, eds.), pp. 100–107, ACM, 2006.

[9] M. S. Ackerman, "The intellectual challenge of CSCW: The gap between social requirements and technical feasibility," Human-Computer Interaction, vol. 15, pp. 181–203, September 2000.

[10] S. Benford, H. Schnädelbach, B. Koleva, R. Anastasi, C. Greenhalgh, T. Rodden, J. Green, A. Ghali, T. P. Pridmore, B. Gaver, A. Boucher, B. Walker, S. Pennington, A. Schmidt, H. Gellersen, and A. Steed, "Expected, sensed, and desired: A framework for designing sensing-based interaction.," ACM Trans. Comput.-Hum. Interact., vol. 12, no. 1, pp. 3–30, 2005.

[11] M. Dodge, R. Kitchin, and M. Zook. How does software make space? Exploring some geographical dimensions of pervasive computing and software studies. Environment and Planning A, June 2009

[12] J. Raper, "The mistakes that satnavs make (and what they don't know)," in Situating Satnav 2, paper session at the Association of American Geographers meeting, 2008.

[13] W. J. Orlikowski, "The duality of technology: Rethinking the concept of technology in organizations," Organization Science, vol. 3, no. 3, pp. 398–427, 1992.

[14] V. L. O'Day, D. G. Bobrow, and M. Shirley, "The social-technical design circle," in CSCW '96: Proceedings of the 1996 ACM conference on Computer supported cooperative work, (New York, NY, USA), pp. 160–169, ACM, 1996.

[15] E. Hutchins, Cognition in the Wild. MIT Press, 2005.

[16] W. Skok, "Knowledge management: London taxi cabs case study," in SIGCPR '99: Proceedings of the 1999 ACM SIGCPR conference on Computer personnel research, (New York, NY, USA), pp. 94–101, ACM, 1999.

[17] A. Crabtree, S. Benford, C. Greenhalgh, P. Tennent, M. Chalmers, and B. Brown, "Supporting ethnographic studies of ubiquitous computing in the wild," in DIS '06: Proceedings of the 6th ACM conference on Designing Interactive systems, (New York, NY, USA), pp. 60–69, ACM Press, 2006.

[18] P. Dourish, “Responsibilities and implications: further thoughts on ethnography and design,” in DUX ’07: Proceedings of the 2007 conference on Designing for User eXperiences, (New York, NY, USA), pp. 2–16, ACM, 2007.

[19] F. Svahn, “In-car navigation usage: An end-user survey on existing systems,” in IRIS27, Falkenberg, Sweden, 2004.

[20] L. Liu and Z. yu Duan, “Activity-based mobility intelligence,” IEEE Pervasive Computing, vol. 7, no. 2, pp. 58–59, 2008.

[21] G. E. Burnett and K. Lee, “The effect of vehicle navigation systems on the formation of cognitive maps,” in Traffic and Transport Psychology: Theory and Application (G. Underwood, ed.), 2005.

[22] N. Chrisman, “Full circle: more than just social implications of GIS,” Cartographica, vol. 40, no. 4, 2005.

[23] P. Atkinson, A. Coffey, S. Delamon, and J. Lofland, eds., Handbook of Ethnography. Sage, 2001.

[24] H. Beyer and K. Holtzblatt. Contextual Design. Defining Customer-Centered Systems. Morgan Kaufmann, San Francisco, 2007.

[25] M. Perry, K. O’Hara, A. Sellen, B. Brown, and R. Harper, “Dealing with mobility: understanding access anytime, anywhere,” ACM Trans. Comput.-Hum. Interact., vol. 8, no. 4, pp. 323–347, 2001.

[26] J. E. Orr, Talking About Machines: An Ethnography of a Modern Job. Cornell University Press, 1996.

[27] S. Kristoffersen and F. Ljungberg, Mobility: from stationary to mobile work, pp. 41–64. Planet Internet, 2000.

[28] S. Tamminen, A. Oulasvirta, K. Toiskallio, and A. Kankainen, “Understanding mobile contexts,” Personal Ubiquitous Comput., vol. 8, no. 2, pp. 135–143, 2004.

[29] S. Elaluf-Calderwood and C. Sørensen, Organizational Agility with Mobile ICT? The Case of London Black Cab Work. Butterworth-Heinemann, 2006.

[30] G. Leshed, T. Velden, O. Rieger, B. Kot, and P. Sengers, “In-car GPS navigation: engagement with and disengagement from the environment,” in CHI ’08: Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, (New York, NY, USA), pp. 1675–1684, ACM, 2008.

[31] C. Aporta and E. Higgs, “Satellite culture: Global positioning systems, inuit wayfinding, and the need for a new account of technology,” Current Anthropology, vol. 46, no. 5, pp. 729–753, 2005.

[32] S. Elaluf-Calderwood and C. Sørensen, 420 Years of Mobility: ICT Enabled Mobile Interdependencies in London Hackney Cab Work. Mobile Work/Technology. 2008.

[33] H. Lorimer and K. Lund, “Performing facts: finding a way over Scotland’s mountains,” The Soc. Review, vol. 51, no. s2, 2003.

[34] S. Benford, R. Anastasi, M. Flintham, A. Drozd, A. Crabtree, C. Greenhalgh, N. Tandavanitj, M. Adams, and J. Row-Farr, “Coping with uncertainty in a location-based game.” IEEE Pervasive Computing, vol. 2, pp. 34–41, July-Sept. 2003.

[35] L. Suchman, Plans and Situated Actions. The Problem of Human-Machine Communication. Cambridge Univ. Press, Cambridge, 1987.

[36] D. D. Woods, Human-centered software agents: Lessons from clumsy automation, pp. 288–293. Washington, DC: National Science Foundation, 1997.

[37] J. Lee and K. See, “Trust in automation: Designing for appropriate reliance,” Human Factors, vol. 46, no. 1, pp. 50–80, 2004.

[38] Y. Yim, “The state of cellular probes,” tech. rep., California Partners for Advanced Transit and Highways (PATH), 2003.

[39] A. K. Lobben, “Tasks, strategies, and cognitive processes associated with navigational map reading: A review perspective,” The Professional Geographer, vol. 56, pp. 270–281, May 2004.

[40] M. Chalmers and A. Galani, “Seamful interweaving: heterogeneity in the theory and design of interactive systems,” in DIS ’04: Proceedings of the 2004 conference on Designing interactive systems, (New York, NY, USA), pp. 243–252, ACM Press, 2004.

[41] E. Rukzio, J. Hamard, C. Noda, and A. D. Luca, “Visualization of uncertainty in context aware mobile applications.,” in Mobile HCI, (New York, NY), pp. 247–250, ACM, 2006.

[42] W. W. Gaver, J. Beaver, and S. Benford, “Ambiguity as a resource for design.,” in CHI (G. Cockton and P. Korhonen, eds.), pp. 233–240, ACM, 2003.

[43] P. Dourish, “Re-space-ing place: "place" and "space" ten years on.,” in CSCW, pp. 299–308, 2006.

[44] G. D. Abowd and E. D. Mynatt, “Charting past, present, and future research in ubiquitous computing.,” ACM Trans. Comput.-Hum. Interact., vol. 7, no. 1, pp. 29–58, 2000..

[45] M. Bierlaire, M. Thémans, and K. A. 2, “Analysis of driver’s response to real-time information in Switzerland,” European Transport, vol. 34, pp. 21–41, 2006.

[46] J. Raper, “Geographic relevance,” Journal of Documentation, vol. 63, no. 6, pp. 836–852, 2007.

[47] M. Arikawa, S. Konomi, and K. Ohnishi, “Navitime: Supporting pedestrian navigation in the real world,” IEEE Pervasive Computing, vol. 6, no. 3, pp. 21–29, 2007.

4. The human implicit interaction with wireless infrastructures as source of travel detection and survey

The ubiquitous technologies that afford us new flexibility in conducting our daily activities are simultaneously providing the means to study our activities in time and space. Indeed, in our case study of a pervasive game (Chapter 2) we used the logs of the mobile devices interactions with a wireless network to position players and share their location. In this chapter, we exploit a similar type of logs to augment travel surveys. So far, research in that domain has often been based on self-declaration methods, such as travel diaries, which have well documented shortcomings such as costs and scale. We show that with the advent of mobile and wireless technologies, and computation capacities, travel surveys can become an integral part of transportation studies. The originality of our approach is that it does not require the use of any location information and runs on mobile phones without hardware modification to report on the travel experiences as they occur, eliminating the recall bias of traditional solutions.

We present this case study in the following paper:

Girardin, F., Nova, N., and Dillenbourg, P. (2009). Detecting air travel to survey passengers on a worldwide scale. Journal of Location-Based Services, 3(3):210–226.

Detecting air travel to survey passengers on a worldwide scale

Fabien Girardin[a,c], Pierre Dillenbourga[a,b] and Nicolas Nova[a]

[a]Simpliquity, Bassins, Switzerland
[b]School of Computer and Communication Sciences, Swiss Federal Institute of Technology Lausanne, Switzerland
[c]Universitat Pompeu Fabra, Barcelona, Spain

Abstract. Market research in the transportation sector is often based on traditional surveys, such as travel diaries, which have well documented shortcomings and biases. The advent of mobile and wireless technologies enables new methods of investigation of passengers' behaviour that can eventually provide original insights into mobility studies. Because these technologies can capture travellers' experience in context and real time, they pave the road for new surveys methods. In this paper, we demonstrate that mobile phones can recognize air travel with a light algorithm that scans their connectivity to cellular networks. The originality of our method is that it does not rely on any GPS-like location information and runs on a large variety of mobile phones. It detects flights on a worldwide scale and asks travellers to report on their travel experiences as they occur, eliminating the recall bias of traditional solutions. Once the system detects a journey, it triggers a flight satisfaction questionnaire that sends answers to a centralized server. This approach respects the traveller's privacy and proved a 97% success rate in detecting flights in a 12-months study involving 6 travellers who boarded on 76 planes.

Keywords: Sensing and activity recognition, mobility detection, transportation study.

1. Introduction

One of the greatest challenges of any survey is to produce high quality and useful data with limited budget and resources. In the past, travel surveys were mostly conducted by mail, face-to-face interviews or methods based on self-declaration such as travel diaries. With the advent of mobile and wireless technologies, combining spatial information systems and computation capacities, travel surveys may assist many types of transportation studies. Research over the last ten years suggests that locative technologies can capture trips that are often missed by traditional methods (Wolf, 2004). Other benefits include: improved accuracy of travel distance and time, routing and experience data previously unobtainable, the ability to capture longer periods of travel and capture more timely data in an economical manner (see Committee on Travel Surveys Methods, Griffiths and al., 2000). With the drop of the costs of incorporating these technologies as hardware prices have declined, multiple approaches for integrating these technologies into travel surveys have been developed. For instance, mobile and wireless technologies afford methods that capture travellers' experience in context and real time, either implicitly, with sensors embarked on a device (e.g. GPS, accelerometers), or, explicitly, by tools for capturing one's own experience (e.g. cameras, sound recorder, in situ questionnaires).

Our work further explores these benefits with a system that allows collecting longitudinal air travel data[9] at a key moment of the travel experience, just after landing. It relies on mobile phones, a device most travellers carry with them when they fly and precisely turn on once they land. Besides the demonstration of a novel methodology for gathering mobility data at a world-wide scale, our contribution focuses on a flight detection algorithm independent from phone network operators and taking into consideration the otherwise intractable privacy concerns. The solution includes a standard digital questionnaire that is activated when the algorithm detects a flight. The triggered survey collects time-dependent air travellers'

---

[9] In our case longitudinal means repeated observations over long periods of time as opposed to along the major axis (latitude, longitude).

behavioural data on their travel choices and experience including willingness-to-pay, itinerary choices and travel behaviour over time. Beyond the survey per se, this collected information is very valuable to develop and calibrate travel behaviour models such as for instance behavioural models of passenger choices. In this paper, we discuss the architecture, design, acceptance and reliability of the developed system evaluated during a worldwide test of the solution. Like any travel survey, our choice of an appropriate solution also considered the trade-offs in cost, data quality, and statistical reliability.

2. Background in travel surveys

Regardless of the transport mean being investigated, fine-grained research on individual travel behaviours and patterns has been rare. The main reason for this lack of research is that traditional techniques such as paper diaries or direct observation are costly and require a lot of human resources. At the same time, the advances in location-sensing and mobile technologies have begun to dramatically change the methodology employed in travel survey methods (Schöfelder, 2003, Shoval and Issacso, 2006). Current approaches to automate the capture of travel behaviours can be categorized into different approaches that rely on individual automatic logging and aggregated tracing - each offering different perspective into human's travel behaviour.

Automatic logging typically records usage information passively without any explicit user intervention. Most research in that direction has been led in the domain of traffic and vehicular data analysis. For example, Wolf et al. (2001) demonstrated a proof of concept study to obtain trip purposes out of Global Positioning System (GPS) data to replace traditional travel diaries (7% of false trip assignment). Similarly, Schönfelder et al. (2002) presented an approach to capture longitudinal travel behaviour by means of GPS. Beside problems inherent to longitudinal surveys (e.g. limited pool of respondents, fatigue effects), the authors identify potential technical drawbacks such as: transmission problems, warm-up times before getting a fix, cost of post-processing of the GPS data. Furthermore, these experiences suggest that the fluctuating quality of traces depend on GPS errors (e.g. premature end of data stream, GPS unit warm-up time), on the GIS database inaccuracies (e.g.

inaccurate coding of the land use in the parcel database) and on hardware issues (e.g. high power consumption of GPS devices) that prevent their use in context-based longitudinal surveys. Finally, there is often an extra piece of hardware that needs to be carried especially for the purpose of the study. To partially solve these issues, the authors highlight the importance of taking the user into account: "*The level of user interaction is believed to be an important issue for the development of future survey design incorporating GPS data collection elements*" (Schönfelder et al, 2002). This implies, for instance, designing the survey to enable individuals to state trip purposes to obtain a broader picture of the detected trips.

Other mobility studies rely on the Global System for Mobile communications (GSM) network as sensors of people's mobility. In a first approach, mobile devices calculate and report their position to a centralized service. The TeleTravel System (TTS) project (Wermuth, 2001) combined a mobile device GSM tracking technology and an electronic travel diary to determine the travel behaviour of the respondents. In addition, some scholars work in the combination of GPS and GSM approaches to produce more complete spatial data (origin, route, destination) when tracking individual's routes (Kracht, 2004). However, they rely on the database knowledge of the cellular network topology and base stations location information to position the mobile devices, limiting the study to a specific area.

Another promising approach relies on aggregated cellular network traffic data as traces of people's movements. The measurement by mobile network operators of traffic intensity and migration of each cell in a GSM network enables capturing movement patterns from mobile phone users. Through this technique Ratti et al. (2006) measure the evolution through space and time of the density of people in a city. Based on similar network data, Aha et al. (2007) link the digital trace of visitors with visited events and locations. The use of aggregated statistics does not present traces of the individual, like her identity or trajectory: in effect the study only estimates the number of mobile phones in a given area of the city at a given time, thus avoiding privacy issues raised by other methodologies (González et al., 2008). Indeed, a major concern here lies in the potential privacy intrusion related to collecting data without individual’s consent (Gutman and Stern, 2007). In studies that do not request people’s permissions, there is an increased risk of identifying people or organizations, especially when the data spatial have a high accuracy. Other issues with this approach include the scalability of the tracking system, for instance, when dealing with a variety of cellular network standards and operators. Table 1 summarizes the issues and constraints for the main approaches for electronic travel surveys.

Approach	Issues and constraints
Individual automatic logging (GPS)	Power consuming, fluctuating data quality, participant fatigue effect to carry extra hardware, limited pool of respondents.
Individual automatic logging (GSM)	Knowledge of the topology of the wireless network topology and base station locations that limits the study to certain regions. Our approach does rely on this information to detect mobility.
Aggregated tracing (GSM)	Agreement with GSM network operator that limits the study to certain regions.

Table 1. Summary of the current electronic travel surveys techniques with their issues and constraints.

Unlike these different ways to capture travel information, our approach relies on the mobile phone to generate “automatic passive” GSM fingerprints and trigger an in-situ questionnaire. It is an hybrid solution of implicit motion detection with the air traveller’s consent and explicit disclosure of the travel experience. The constraints that led to this solution are detailed below.

3. Design considerations

We developed an all-terrain solution for which more rustic technologies such GSM fingerprinting for detecting mobility and Short Message Service (SMS) for survey data communication were preferred. The originality of our approach was to consider these practical constraints not as peripheral concerns to shape the delivery of technology but as the definition of the problem per se. Particularly, the system had to detect flights “*accurately*” worldwide in respect to travellers’ “*privacy*”. "Worldwide" means "*any country*", "*anywhere*" in the country and "*any user*". We develop these dimensions below.

3.1. Any country

"Any country" means "any operator" and "any law". “Any operator" excludes any advanced data communication; this led us to send data through SMS, the most widely used data application on the planet, with 2.4 billion active users. In addition, it also excludes any solution that requires an agreement with a cellular network operator. "Any law" implies that our solution has to be compatible to the most restrictive rules in term of tracking. This excludes any solution that does not rely uniquely on standard phone components to detect its own mobility. In addition, it is not sufficient to ask travellers once for all if they agree to reveal their location. In contrast, for each flight detection, it is crucial to ask explicitly whether the participant agrees to reveal her location and to abort the questionnaire if she answers negatively.

3.2. Anywhere

Anywhere excludes any GPS-based system since GPS does not work well in covered area such as airports. In contrast, GSM is the most widespread cellular telephony standard in the world, with deployments in more than 200 countries. As of January 2009, the GSM family of technologies has 3 billion subscribers and 80% of the world market (GSM Association, 2009). For setting up this project, we interviewed 228 UK residents departing from London Heathrow and Gatwick in early July (128 for leisure and 100 for business). The aim of this survey was to gather information on mobile cell phone usage to make sure that an optimal amount of of travellers would accept our solution. While this survey does not pretend to be representative of the population that travels by air, it gave us the necessary information to support the methodological and technical choices of this proposal. We found that 96% of respondents use a GSM mobile phone, 88% had it with them at the airport and 71% were sure to use it at their destination.

3.3. Any user

"Any user" means "any contract" and "any phone". "Any contract": the solution has to work with any type of contract with a mobile operator, which includes prepaid cards that often have roaming restrictions. This was another argument for using SMS. SMS is part of the GSM series of standards since 1985. Since then, support for the service has expanded to include alternative mobile standards such as ANSI CDMA networks. "Any phone" means that it would run on any selected participant's mobile phone. We chose Symbian[10] as the most promising standard at that time within the complex "jungle" of operating system for mobile devices[11]. "Any user" also means undisciplined air passengers who do not switch their phone off in the plane.

3.4. Accurately

"Accurately" means the algorithm has to minimize two types of errors: under-detection of flights (i.e. the traveller flew but the algorithm does not detect it) and over-detection (i.e. the algorithm infers the traveller flew while it is not the case). Under-detection reduces the quality of recorded data but over-detection is only annoying for the participants if it occurs frequently. In fact, some over-detection can be beneficial, if not too frequent, since it reminds travellers they participate to a survey. In our solution, the survey asks the participants to confirm that they indeed have taken the plane. When they have not, the system records the information to avoid repeating the mistake in the same cellular network configuration.

3.5. Privacy

A true passive logging system will not only need the approval of the participants but, for some countries, the approval of the Government. The term tracing can be interpreted as electronically following the movements of a human being without him noticing it. In contrast, a system will not be considered as tracing and will fall into normal mobility and transportation research activity if it can: a) detect travel only b) tells the traveller that this fact is to be communicated c) and asks for confirmation with a question such as "please confirm that this information can be communicated".

In the remainder of this paper, we first describe the solution we implemented and its architecture. Particularly, we present the resulting rule-based algorithm to detect air travel from GSM

---

[10] http://www.symbian.org/

[11] Symbian counts for 46.6% of market share sales for operating systems used in smartphones in Q3 2008. Source Canalys report: http://www.canalys.com/pr/2008/r2008112.htm

fingerprints. Subsequently, we describe the results of the worldwide field experiment performed over a 12 months period. We compare this work with similar approaches and conclude with a discussion on the contributions of this study and their implications for future works.

4. Implementation

A GSM base station is typically equipped with a number of directional antennas that define sectors of coverage, or cells. In our study, we built a software mobility sensor based on wireless signals received by the mobile phone. We wrote a custom application for Symbian mobile phones to measure and record the surrounding GSM radio environment at a constant interval of 15 minutes. We will see later on that the choice of this interval is very important. Each reading generates a GSM fingerprint called a Location Area Identity (LAI) that uniquely identifies a location area within any mobile network. More specifically LAI comprises the Mobile Country Code (MCC), Mobile Network Code (MNC) and Location Area Code (LAC) (Figure 1).

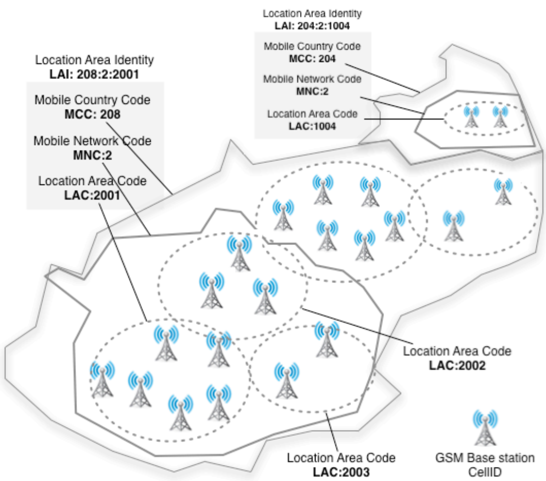

Figure 1. A GSM network in a country assigned with a Mobile Country Code (MCC). Within this country each mobile operator is assigned a unique Mobile Network Code (MNC). The operator deploys its GSM base stations and aggregate them in specific areas indentified with a unique Location Area Code (LAC). Our implementation exploits these unique 3 codes that form a LAI (Location Area Identity), discarding the CellID of the base stations, to detect the mobility of air travellers.

With an analysis of the sequence of LAIs, phones can detect their mobility without interaction with a central service. We refer to 'triggers' as the criteria that the phone software uses to detect that the traveller has taken the plane.

4.1. System architecture

The architecture of the software is divided into five modules (Figure 2). When the mobile phone is switched on, an autostart module (module 1) waits for the user to unlock the device (i.e. enter her PIN code) and launches the GSM Tracker module (module 2) after a fixed delay of 45 seconds. This delay has been set-up to avoid interferences with other applications and to leave the necessary time for the mobile phone to establish a connection with a local base station. The tracker module scans the GSM network fingerprints in a scheduled interval of 15 minutes. The travel trigger module (module 3) uses an algorithm to analyze the retrieved LAI. In case the algorithm does not detect a travel, the last 2 retrieved LAIs are kept as a pair in a non-travel list. If a travel is detected, a questionnaire module (module 4) starts with a graphical interface that appears on the device's display. Questions are loaded from a text file and answers are sent via SMS by the communication interface module (module 5). The SMS mechanism we developed uses a fail-over technique that handles the message to be sent. In case of lack of network connectivity, the message stays in a queue that empties when the mobile phone return under GSM coverage or roaming accessibility. The system keeps on trying to send the data every 30 minutes until successful delivery.

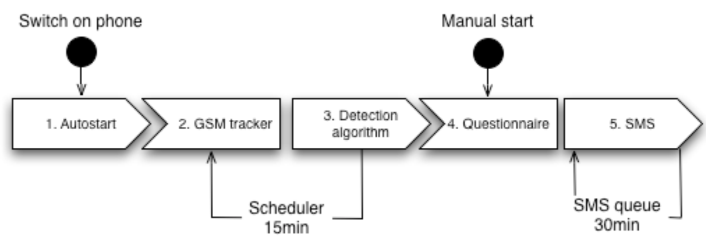

Figure 2. The five modules of the system architecture.

For privacy concerns, we let users the possibility to exit from the system, if they do not want their mobility to be known in any way, even by their own mobile phone. Therefore we also give users the opportunity to manually launch the questionnaire.

4.2. Software implementation

We decided to implement the system for the Symbian OS operating system because, at the time of development, it was the unique platform that allowed to 1) programmatically start an application on a mobile phone boot mechanism (for the Autostart module) easily call the execution of other modules (to start the GSM tracker, the questionnaire and SMS modules when necessary), 2) use a "scheduler" to systematically call a module (the GSM tracker every 15min) and finally 3) get access to the device network interface for the GSM tracker to retrieve the current LAI. In contrast, these requirements were impossible and complicated to develop on JavaME , a platform generally easy to program on.

The walled garden context in the mobile industry challenged the implementation of the system. Indeed, we found out that the developed code would run appropriately on the diversity of platforms. For instance, some mobile phone manufacturers did not properly implement the Symbian operating system or some mobile operators disabled some features (e.g. programmatic access to the network interface). Therefore, we had to develop different codebases according to some mobile phones or operators unpublished limitations. Similarly, we discarded any solutions that relied on proprietary software (such as Google MyLocation) that does not guarantee an open API.

The strict management of power consumption of the system was another constrain of the implementation. It prevented us in considering opportunistic scenarios to implicitly communicate the travel data. It is another reason why SMS was preferred over other communication interfaces such as Bluetooth or WiFi that are very energy demanding when scanning for their environment. Moreover, the implementation of these modules would have added unnecessary complexity (e.g. with additional code bases) to our simple solution. In our longitudinal evaluation, the fractional use of the mobile phone processor to launch the GSM tracker every 15 minutes remained unnoticed..

4.3. Air travel detection algorithm

The algorithm detects air travel with the same principle as fingerprint-based location systems (Hightower et al., 2005): the radio signals observed from fixed sources are consistent in time, but variable in space. Thus, given a series of wireless scans with similar fingerprints, we conclude that the phone is not moving. Similarly, we interpret changes in the sequence of fingerprints as indicative of motion. The tracker module scans the GSM network at in interval of 15 minutes. The retrieved LAI uniquely identifies a LA (Location Area) within any PLMN (Public Land Mobile Network). Note that the LAI does not contain the identifier of the base stations (CellId), but that is not necessary since there we are not looking for finer network information. Indeed, depending on the urban density of an area, a LAC can extend from few kilometres to around 100 kilometres.

Our algorithm is based on the principle that ground transportation enables continuous connection between the cellular network base stations and the traveller's phone, while a flight leads to an interruption of connection (Figure 3).

After the collection of weeks of LAIs, we were able to simulate and refine a very simple algorithm that replaces complex GPS approaches by common sense balance of two types of mistakes, the false positive and the false negative. The algorithm minimizes the risk of false negatives (i.e. the user has indeed taken a flight that has not been detected) but augments the risk of false positive as explained below. During ground transportation, the user may loose connection for a few minutes, for instance in a road tunnel. This will not be considered as a travel as long as the time without connection is below 30 minutes. In cases where the time without connection is longer and associated with a change of LAI, for instance a long metro ride, we face a false positive. In this case, the system prompts a question on the mobile phone "*It seems that you have taken a plane, is that correct?*". In response, the participant answers negatively and the system adds the LAI pair to the non-travel list. Hence, it learns not to prompt the questionnaire anymore for that specific sequence. False negative cases will hence quickly disappear from any frequent travel pattern.

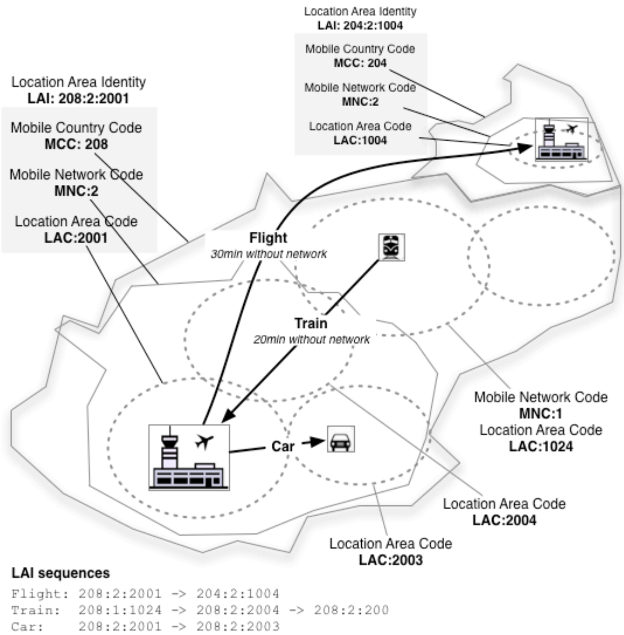

Figure 3. The algorithm analyses the sequences of LAIs. This figure shows 3 examples: In flight, the mobile phone roams from one country code to another. If our software does not retrieve any LAI within 30 minutes, it detects an air travel. In a train, the mobile phone moves within different network providers and area codes. No survey appears if the disconnection periods do not exceed 30 minutes. Similar scenario takes place for a car that moves within different location areas.

We first describe how this principle has been implemented and then what are its exceptions (Figure 4). The algorithm obviously decides that if the fingerprint hasn't changed (LAIn = LAIn-1), the phone user has not taken a plane since a LAI does not cover two connected airports. Second, the algorithm checks if the pair of fingerprints [LAIn-1, LAIn] is present in non-travel lists. This list is central to our algorithm. Third, according to the previously mentioned principle, the algorithm decides that if the phone did not succeed connecting a base station during 30 minutes or more, the user has probably taken a flight.

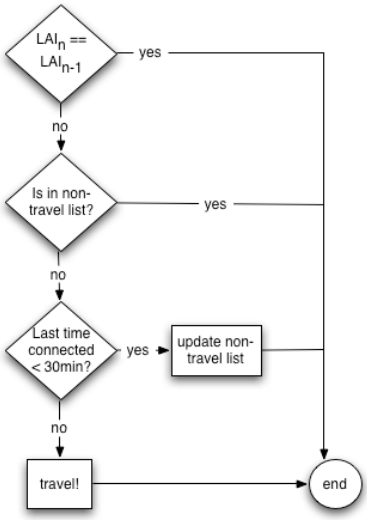

Figure 4. Travel Trigger algorithm

If the last successful reading took place within less than 30 minutes, the system records a list of LAI pairs, called non-travel list that contains all consecutive locations between which no flight occurred. Figure 5 is an example of a non-travel list generated after 3 weeks of travel from an individual living in Spain and sometimes flying to Switzerland. It illustrates the fact that most of the non-travel events are due to a hop to a proximate LAC and transition of MNC handling connectivity within the same country (MCC).

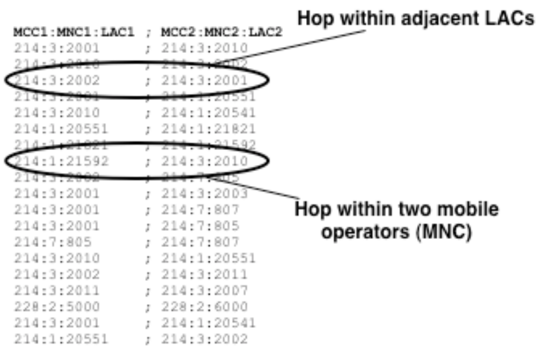

Figure 5. Example of a non-travel list. Each line constitutes a pair of "proximate" LAIs with the format MCC1:MNC1:LAC1;MCC2:MNC2:LAC2. This example show hops within adjacent LAC and mobile operators. For privacy concerns, we do not associate any time to these records. In addition, it must be stressed that the mobile phone does not communicate this data.

4.4. In-situ questionnaire

The survey component of the project consists in a short questionnaire that starts immediately after travel detection to collect passengers' travel experience. More specifically, two questions are first prompted to the user. First, the system asks her to confirm the fact that she has taken the plane. Second, the system asks the traveller to confirm explicitly the fact that she accepts her trip information to be communicated to the centralized survey server. It may be the case that the participant is busy with passport or custom controls or looking for his or her luggage. In other situations, she may start answering questions and then be interrupted by a phone call or any external event. In both case, the application regularly prompt the traveller to complete the questionnaire.

The questionnaire supports several forms of questions, such as single choice, multiple choice or text entries. An example of the text file would contain a 1-minute questionnaire on the a) acceptance of record of location; b) flight number; c) overall opinion on the flight; d) overall feeling after the flight

4.5. Data communication

Once the questionnaire has been completed, the phone compiles the answers and the LAI information within a text message and sends them via SMS to a centralized server, as for example:

```
Survey:65535 FlightNo:LX1953 LAI1:{30-04-
2006,19:14:29,228:2:5000} LAI2:{30-04-
2006,20:14:32,214:1:20541} Answers{1,0,3}
```

This data is then stored in the survey database. The advantage of SMS over any other data communication solution is first that they generate very low costs (for this type of study that collects a limited amount of data), and second that they work in limited connectivity situations with a basic GSM networks. Finally, if there is no connection, the SMS will be sent later when the connection is restored. For instance, one traveller flew to the West Coast of the USA with a Swiss pre-paid SIM card. All his flights were correctly detected on his mobile phone and the participant answered the surveys. However, since his operator did not have roaming agreement with any American operator in that region, the survey data were received at his return to Switzerland. The evaluation period served us in testing and collecting further practical experiences.

5. Evaluation

The algorithm and data collection process have been tested and improved for 12 months between February 2006 and February 2007. GSM logs have been collected from multiple persons and types of phones. 6 frequent travellers, familiar with the project, were involved in the project as participants. 3 used their own mobile phone and 3 others used a phone we gave them and on which we had pre-installed the software. They were not genuine users, although we noticed that when doing professional or family trips, they completely forget about the travel detection application and tend to behave normally until the phone vibrates and rings to ask travel questions. We benefited from the familiarity of the participants to the project to request some of them to not keep their phone switched on during the flights where it matters, such as in short continental flights.

Participants used Subscriber Identity Module (SIM) cards from Switzerland (from where the 3 major operators have been tested), Spain (1 operator) and the UK (1 operator) on Symbian series 60 phones. They boarded 76 planes with our software, connecting 27 airports in Europe and North/Central America, Asia and Australia as represented on Figure 6.

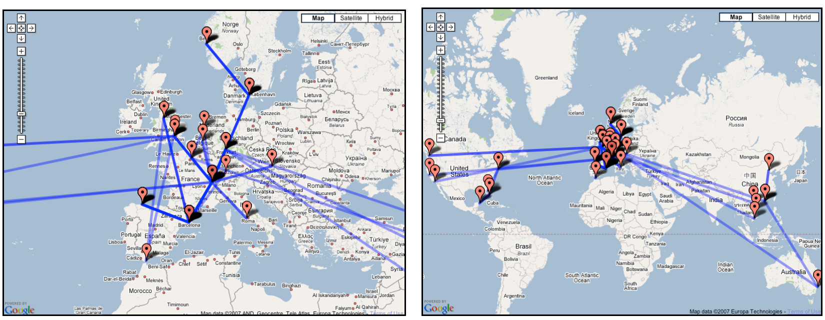

Figure 6: European (left) and Worldwide (right) detected travels. Maps generated from the SMS received by the centralized server.

First, the evaluation of the system showed that false positives did not annoy nor was portraying the system as unreliable technology.

Nevertheless, further empirical evidence would be necessary to fully confirm that behaviour.

Second, the algorithm has been successful in detecting flights and avoiding "false negative" in real-world settings. Among the 76 flights, 74 air travels were properly detected (97%) and data correctly reported to the centralized survey server. We had the case of two undetected flights. One because, the traveller did not switch on his phone on a stop-over therefore missing the data on the first flight. The other undetected flight took place on a short flight in which the tester did not switch off his phone. This suggests that the main limitation of the algorithm lies in the possible behaviour of some passengers, which correspond to these two cases.

5.1. Stop-overs

We noticed that stop-overs are potentially problematic to detect with passengers not switching on their phones. If the traveller has a short stop-over between two flights, it might be the case that she does not turn on his mobile phone. In this case, she will receive the questionnaire at the end of the second flight and responds the survey on the two segments of his journey.

5.2. Short flights

Similarly phones not switched off in the plane are prone to not detect flights, particularly for short flights. When a plane stays at a low altitude over powerful cellular networks, it may be the case that the phone continues to connect to base stations during the flight. This scenario happened on a test flight from Geneva, Switzerland to Munich, Germany.

6. Related works

Works related to our system cover three themes; motion detection with wireless fingerprints; activity and place recognition from motion detection and in situ surveys triggered with activities and places recognition algorithms.

6.1. Mobility sensing and motion detection with wireless networks

Similar to our approach, research groups have been investigating mobility pattern detection without the use of spatial coordinates as a location indicator, but instead sets of consistently heard radio transmitters. Asakura and Iryo (2007) determined it by interpreting changes in the set of nearby base station and signal strengths of the phones as indicative of position and motion of their owners. Sohn et al. (2005) gathered GSM network trace data over a period of one month, logging a total of 249 walking events and 171 driving events. Their methods show that GSM-based sensing may provide enough activity information for some applications, without the overhead of requiring additional sensors. Our work further proves that motion detection using GSM is feasible and works well throughout people’s long distance travels.

In addition, this research avenue has been investigated in the field of lifelogging services in the last five years. The underlying idea of these applications lies in the recording of every digital interaction that can be captured by cell phones or mobile devices. It then allows users to access, share and search personal memories. From all the data that can be collected, spatial movements are of course of interest to researchers. For instance, an application such as LifeTag (Rekimoto et al., 2007), based on WiFi tracking, can also be seen as a solution for mobility sensing. As argued by the authors, the advantage of such method is that WiFi allows indoor-tracking (as opposed to GPS). We can also wonder whether WiFi, if the infrastructure is properly set, can enable finer-grained positioning than GSM.

6.2. Place recognition

In addition to mobility surveys, investigation has been performed in the field of place detection. The general problem of recognizing significant places from location data has received much attention. Hightower et al. (2005)’s BeaconPrint algorithm finds repeatable sets of GSM and Wi-Fi fingerprints to automatically learn the places someone go and then detect when they return to those places. Similarly Zhou et al. (2005), looked at the relationship between place discovery and importance and found that those places judged meaningful by the subject were much easier to detect. Liao et al.

(2003) made an attempt to automatically determine which of the important places is the user's home. They used machine learning on labelled place data to achieve 100% classification accuracy in finding locations of their five subjects' home and work places. Nurmi and Bhattacharya (2008) went a step further with an algorithm that can accurately identify places without temporal information.

6.3. In-situ questionnaire

The ability to detect motion and recognize place enabled the development "context-triggered sampling" (Froehlich et al. 2006). This technique, pioneered by MIT's Context-Aware Experience Sampling tool for the PDA (Intille et al., 2003), uses sensors to infer context to trigger a brief survey and capture data on participants' thoughts, feelings, and behaviours as they are experienced. It has several advantages when compared with traditional sampling methods, such as random or time-based triggering. For example, context-triggered surveys are much more likely to occur during events that are of interest to capture offering a distinct methodological advantage since they do not rely on the reconstruction of information from memory or logs therefore minimizing recall bias of self-reporting methods. Additionally, the computer can continuously save context data; allowing the researcher to cross-check answers with sensor data and uncover behavioural patterns not initially considered.

However, these solutions use extra sensors and do not capture the travel experience because restricted to very defined areas. To our knowledge, the method we propose is original because it runs worldwide, on any GSM network, it collects and reports survey data on air travel experience – with respect to survey participants' privacy - at a key moment of the travel experience, just after a landing.

7. Conclusion and future work

Detecting travel is difficult due to the challenge of building informative, yet unobtrusive algorithms that respect privacy. GPS sensing is available a low percentage of time of a typical person's day, as it needs a wide swath of clear sky to sense enough geostationary satellites (LaMarca et al., 2005). Moreover, it is very power consuming that makes it an unpractical solution for longitudinal surveys. Several tests have been conducted to log personal movements using GSM mobile phones. Some advantages of mobile phones relative to a GPS system is that they function underground and inside buildings, and the density of cellular base stations is higher in the most dense urban areas. Also, the market penetration of cellular phones is very high, so the cost of equipment is low. Recently, several studies tested the use for tracking personal travel, especially as many mobile phones already have the capability of recording and storing the position over time. They show that the position accuracy afforded by cellular phone is lower than GPS. Hence, while gross measurement of travel is achievable, specific routes or travel modes are less likely to be determined without greater participant interaction.

Our contribution demonstrates a novel methodology for gathering mobility data at a world-wide scale, contrasting with traditional travel survey methods. We have demonstrated the feasibility of using a basic, unmodified, GSM phone, owned by 3 billion subscribers worldwide, to recognize air flights. Our solution applies to all areas with GSM coverage (860 networks in 220 countries and regions in early 2009[12]). Our algorithm and data collection process has been evaluated over 12 months with a 97% successful flight detection rate (74 out of 76 flights) When extended to a larger scale, the collected information could become very valuable to develop and calibrate travel behaviour models such as for instance behavioural models of passenger choice. However, more empirical evidences are necessary to test the robustness of the system and collect more observation of participants' perception of false positives. Nevertheless, our contribution shows that:

1) Simple behavioural patterns, captured in our case as the LAIs pairs, constitute a powerful alternative to complex technological developments for longitudinal travel survey without modifying the habits of the participants. This approach could be extended for detecting other types of

---

[12] Source GSM Association
http://www.gsmworld.com/roaming/gsminfo/index.shtml

transport (e.g. train, boats, ski) on different mobile devices such as watches and cameras, not by using with the same algorithm, but by applying the same principles as in our light algorithm.

2) National regulations regarding tracing people could be an obstacle to any travel detection system. At the opposite, a system that warns the traveller that this fact is to be communicated through as survey is not considered as "tracing" and falls under normal travel and transportation research activity.

On a final note, while many computer scientists and engineers consider practical constraints as detrimental to the elegance of technological solutions, we instead view them as opportunities to rethink solutions which eventually have to change over time. The airlines rules will change the social practices and require a revision of our algorithm, with respect to the use of mobile phone on board, the cost of communications, and cultural habits. For instance, lately, there is a new movement to allow passengers to use their own mobile phones among several airlines launching their own in-flight services (e.g. using OnAir[13]). In consequence, our system will certainly need to adapt to this specifically in a near future. Therefore, a major advance would be that the data collected by survey participants allow to develop a permanently updated database of GSM base stations for base stations installed in planes and in all airports worldwide. This extremely valuable database would be progressively enable simpler flight detection techniques for future transportation studies.

References

Ahas, R., Aasa, A., Silm, S., and Tiru, M. (2007). Mobile positioning data in tourism studies and monitoring: Case study in tartu, estonia. In Marianna Sigala, L. M. and Murphy, J., editors, *Information and Communication Technologies in Tourism 2007*, Ljubljana, Slovenia. Springer Vienna.

Asakura, Y. and Iryob, T. (2007). Analysis of tourist behaviour based on the tracking data collected using a mobile communication

[13] http://www.onair.aero/

instrument. *Transportation Research Part A: Policy and Practice*, 41(7):684–690.

Froehlich, J., Chen, M. Y., Smith, I. E., and Potter, F. (2006). Voting with your feet: An investigative study of the relationship between place visit behavior and preference. In Dourish, P. and Friday, A., editors, Ubicomp, *Lecture Notes in Computer Science*, pages 333–350. Springer Berlin / Heidelberg.

González, M. C., Hidalgo, C. A., and Barabási, A.-L. (2008). Understanding individual human mobility patterns. *Nature*, (453):779–782.

Griffiths, Robert, Richardson, A.J., Lee-Gosselin, Martin E.H. (2000). Travel Surveys, Transportation in the New Millennium, Transportation Research Board (http://gulliver.trb.org/publications/millennium/00135.pdf)

Gutman, M. and Stern, P., editors (2007). Putting People on the Map: Protecting Confidentiality with Linked Social-Spatial Data. National Academies Pres

GSM Association (2009), Market Data Statistics, http://www.gsmworld.com/newsroom/market-data/market_data_summary.htm (last visited, January 28 2009)

Hightower, J., Consolvo, S., LaMarca, A., Smith, I., and Hughes, J. (2005). Learning and recognizing the places we go. *In Proceedings of the Seventh International Conference on Ubiquitous Computing (Ubicomp 2005)*, Lecture Notes in Computer Science, pages 159–176. Springer-Verlag.

Intille, S. S., Rondoni, J., Kukla, C., Ancona, I., and Bao, L. (2003). A context-aware experience sampling tool. In *CHI '03: CHI '03 extended abstracts on Human factors in computing systems*, pages 972–973, New York, NY, USA. ACM.

Kracht, M. (2004). Tracking and interviewing individuals with gps and gsm technology on mobile electronic devices. In *Seventh International Conference on Travel Survey Methods*.

Liao, L., Fox, D., and Kautz, H. (2005). Location-based activity recognition using relational markov networks. *In Proc. of the International Joint Conference on Artificial Intelligence (IJCAI)*

LaMarca, A., Chawathe, Y., Consolvo, S., Hightower, J., Smith, I. E., Scott, J., Sohn, T., Howard, J., Hughes, J., Potter, F., Tabert, J., Powledge, P., Borriello, G., and Schilit, B. N. (2005). Place lab: Device positioning using radio beacons in the wild. In Gellersen, H.-W., Want, R., and Schmidt, A., editors, *Pervasive*, Lecture Notes in Computer Science, pages 116–133. Springer.

Nurmi, P. and Bhattacharya, S. (2008). Identifying meaningful places: The non-parametric way. In *Pervasive*, pages 111–127.

Ratti, C., Pulselli, R. M., Williams, S., and Frenchman, D. (2006). Mobile landscapes: Using location data from cell-phones for urban analysis. *Environment and Planning B: Planning and Design*, 33(5):727 – 748.

Rekimoto, J., Miyaki, T. and Ishizawa, T. (2007). LifeTag: WiFi-based Continuous Location Logging for Life Pattern Analysis. *3rd International Symposium on Location- and Context-Awareness (LOCA2007)*, pp.35-49

Schöenfelder, S., Axhausen, K., Antille, N., and Bierlaire, M. (2002). Exploring the potentials of automatically collected gps data for travel behaviour analysis - a swedish data source. In Möltgen, J. and Wytzisk, A., editors, *GI-Technologien für Verkehr und Logistik*, number 13 in IfGIprints, pages 155–179. Institut für Geoinformatik, Universität Münster.

Schönfelder, S. (2003). Between routines and variety seeking: The characteristics of locational choice in daily travel. In *10th Intl Conf on Travel Behaviour*.

Shoval, N. and Isaacson, M. (2006). Tracking tourists in the digital age. In *The Annals of Tourism Research*.

Sohn, T., Li, K. A., Lee, G., Smith, I. E., Scott, J., and Griswold, W. G. (2005). Place-its: A study of location-based reminders on mobile phones. In Beigl, M., Intille, S. S., Rekimoto, J., and Tokuda, H., editors, *Ubicomp*, volume 3660 of Lecture Notes in Computer Science, pages 232–250. Springer.

Wermuth, M., Sommer, C., and Kreitz, M. (2003). Impact of New Technologies in Travel Surveys, chapter 27, pages 455–482. Pergamon, Oxford.

Wolf, J. (2004). Applications of new technologies in travel surveys. In *7th International Conference on Travel Survey Methods* in Los Suenos, Costa Rica.

Wolf, J., Guensler, R., and Bachman, W. (2001). Elimination of the travel diary: an experiment to derive trip purpose from global positioning system travel data. *Transportation Research Record*, (1768):125–134.

Zhou, C., Ludford, P. J., Frankowski, D., and Terveen, L. G. (2005). An experiment in discovering personally meaningful places from location data. In *CHI Extended Abstracts*, pages 2029–2032.

5. User-generated ubiquitous geoinformation as evidences of tourist dynamics

The approach of the previous case study (Chapter 4) focused on logs generated from individuals' implicit interactions with wireless infrastructures to perform travel surveys on a worldwide scale. This chapter considers other user-generated ubiquitous geoinformation to provide more empirical evidences of travellers' density and flows.

In a case study of Florence and Rome, Italy, we explore the value of explicitly disclosed geographically-referenced photos and implicitly-generated records of mobile phone network usage. We show that the analysis of these spatio-temporal data can supply high-level human behaviour information valuable to social scientists, urban planners and local authorities. Based on the techniques of the replay tool employed in our pervasive game (Chapter 2), we designed "Urban dynamics" a software that performs novel data collection and analysis techniques augmented with visualization and mapping tools. This software illustrates the potential of user-generated electronic trails to remotely reveal the presence and movement of a city's visitors, their spatio-temporal presence, inbound-outbound trajectories, internal flows, and semantic description. For instance, it helped comparing the significance of aggregated cellular network traffic data with georeferenced photos and reveal different presence of tourists in Rome.

We present this case study with the following papers:
Girardin, F., Fiore, F. D., Ratti, C., and Blat, J. (2008). Leveraging explicitly disclosed location information to understand tourist dynamics: A case study. *Journal of Location-Based Services* 2, 1, 41–54.

Girardin, F., Calabrese, F., Dal Fiore, F. , Ratti, C., and Blat, J. (2008). Digital footprinting: Uncovering tourists with user-generated content. *IEEE Pervasive Computing*, 7(4):36–43.

Leveraging Explicitly Disclosed Location Information to Understand Tourist Dynamics: A Case Study

Fabien Girardin[a], Filippo Dal Fiore[b], Carlo Ratti[b] and Josep Blat[a]

[a]Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain
[b]Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, USA

Abstract. In recent years, the large deployment of mobile devices has led to a massive increase in the volume of records of where people have been and when they were there. The analysis of these spatio-temporal data can supply high-level human behavior information valuable to urban planners, local authorities, and designer of location-based services. In this paper, we describe our approach to collect and analyze the history of physical presence of tourists from the digital footprints they publicly disclose on the web. Our work takes place in the Province of Florence in Italy, where the insights on the visitors' flows and on the nationalities of the tourists who do not sleep in town has been limited to information from survey-based hotel and museums frequentation. In fact, most local authorities in the world must face this dearth of data on tourist dynamics. In this case study, we used a corpus of geographically referenced photos taken in the province by 4280 photographers over a period of 2 years. Based on the disclosure of the location of the photos, we design geovisualizations to reveal the tourist concentration and spatio-temporal flows. Our initial results provide insights on the density of tourists, the points of interests they visit as well as the most common trajectories they follow.

Keywords: spatio-temporal data analysis; geovisualization; location-disclosure; location-based services

1. Introduction

In the past years, research in location sensing and tracking has been dominated by figuring out where persons and objects are in space (see Hazas et al., 2004 for a review). The wide adoption of the mobile and wireless technologies often referred to as Location-Based Services allows people a new perception of their surrounding physical and social spaces. In parallel, the records of where and when people have been (i.e. spatio-temporal data), produced by these services, have led to improve the understanding of different aspects of mobility and travel. The analysis of these data helps to recognize the modes of mobility (Sohn et al., 2006), define significant places (Ashbrook and Starner, 2002), cluster tourist routes in a city (Asakura and Iryob, 2007), infer travel purposes (Wolf, 2001) or predict a driver's destination as a trip progresses (Krumm and Horwitz, 2006). Ratti et al. (2006) benefit from people's experience of mobile devices to gain a more thorough understanding of urban environments, and this is the field of application undertaken in this paper.

First, let us remark that the large spatio-temporal logs can be seen as personal, as we explain later and their analysis can provide urban planners, local authorities and designers of location-based services with information on how a city gets used by different groups complementing current data sources, which are normally used as the basis of decision and policy making. Knowing who populates different parts of the city at different times can lead to the provision of customized services (or advertising), the rescheduling of monuments opening times or the reallocation of existing service infrastructures. From a quite different perspective, city users themselves could be aware of the current ways in which they populate the city, and adopt different strategies as a result.

Our approach takes advantage of the recent explosion in the use of capture devices (e.g. mobile phones, digital cameras) and collaborative web platforms to share their content (see Torniai et al., (2007) for a review). This people-generated information provides large amounts of digital data linked to the physical world. Recent research showed the potential of the geographically annotated material available on the Web. For instance, Ahern et al., (2007) and Snavely et al. (2006) developed means of world exploration via photos and maps to foster "virtual tourism". Using a similar dataset, Rattenbury et al. (2007) showed that the location and time metadata associated with photos and their tags enable the extraction of "place" and "event" semantics. In our study, we focus on the sense of presence extracted from a collection of photographs captured in trips. We consider that uploading, tagging and disclosing the location of a photo can be interpreted as an "I was here" statement indicating the physical presence in space and time. By extension, we propose that people-generated geographically referenced information provide new insights on how people travel and experience the city.

The validation of the relevance of this concept takes body in the Italian Province of Florence. The local authorities of that region aim at better understanding the tourist flows travelling across the cities boundaries. So far, they have been using classical survey-based hotel and museums frequentation data to know where tourists of different nationalities prefer to spend their time, hence money. However, they lack observations of the mobility, nationality and quantity of the "day trippers", that is the tourists who visit Florence but are "invisible" in the data, as they do not sleep in town. In consequence, we retrieved 81017 photos taken in the region by 4280 photographers over a period of 2 years from the popular photo-sharing web platform Flickr[14]. Based on the time and the disclosed location of the photos, we extracted records of the people presence and movements; performed statistical analysis and designed geovisualizations. This exploratory visual analysis was used as a mean of preliminary investigation. In fact, the results go far beyond the initial expectations of collecting clues on "day trippers" activities, as we shall see, providing new insights, and even a novel paradigm of urban geography.

In the remainder of this paper, we discuss first current work on mobility data collection and constraints to perform travel surveys. These shortcomings suggest that the research community should investigate and evaluate new data and perspectives. Then, we propose a novel approach that takes advantage of spatio-temporal

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

data generated by tourists when publicly sharing their photos on the world-wide web. Next, we describe the types of data that can be collected and their meaning. Afterwards, we present the preliminary results of our analysis supported by geospatial visualizations. They highlight the ability to quantify the concentration of tourists and their movements over time through the major areas of interests. Finally, we conclude with a description of the implications from this case study and discuss the meaning for future work.

2. Related work and their limitations

The recent emergence of location technologies and techniques favoured the development of new approaches to capture and analyze people's mobility (see Wolf, 2004 for a survey). The aim has been to replace traditional travel diaries, paper-and-pencil interview, computer-assisted telephone interviews, and computer-assisted-self-interview, by automatically collecting mobility data. For instance, Wolf et al. (2001) proved the feasibility of using Global Positioning System (GPS) data loggers to improve the quality or completely replace traditional questionnaires. However, this type of mobility survey faces the problem inherent to longitudinal studies such as recruiting a pool of respondents or preventing any fatigue effects. Besides the privacy concerns of continuously and precisely tracking people, Schoenfelder et al. (2002) and Stopher et al. (2003) identify the potential technical drawbacks of a GPS-based approach. They list transmission problems, warm-up times before getting a valid position, and the cost of post-processing the GPS data as issues that impair the quality of the survey. Indeed, Wolf et al. mention that the equipment packages deployed for their pilot study had a lot more problems than anticipated: the units and cabling used were not optimized for durability, resulting in the loss participants due to problems with equipment performance and user operations.

Other mobility studies relied on the mobile phones use of the Global System for Mobile communications (GSM) network to generate mobility data. In a first type of approach, the mobile devices calculate and report their position to a centralized service. The TeleTravel System (TTS) project (Wermuth, 2003) combined a mobile device GSM tracking technology and an electronic travel diary to determine the travel behaviour of the respondents; while

Asakura and Iryob (2005) determined it by interpreting changes in the set of nearby towers and signal strengths of the phones as indicative of position and motion of their owners; Froehlich et al. (2006) augmented the GSM mobility data with context-triggered in-situ survey in which panelists rate the place they are in to study travel routines. A second approach employs the measurement by mobile network operators of traffic intensity and migration of each cell in a GSM network to capture the movement patterns of mobile phone users. Through this technique Ratti et al. (2006) measure the evolution through space and time of the activities in a city to support urban planning. Based on comparable network data, Ahas et al. (2007) retrospectively link the digital track of visitors with visited events and locations retrospectively. While this approach scales because it does not rely on a costly software or hardware deployment, it fails in capturing individual traces. A third approach relies on the deployment of Bluetooth enabled systems. Recent studies have been able to establish the flow of people at strategic locations (O'Neill et al., 2006) as well as to recognize daily user activities and to identify socially significant locations (Eagle and Pentland, 2006).

However, there are several key issues when using technologies to collect travel behaviours. A major concern consists is the privacy and ethical issues related to collecting data without individual's consent (Gutman and Stern, 2007). Indeed, there is an increase in the risk of identifying people or organizations when their data spatial precision improves. Other issues include the length of the survey (e.g. to prevent fatigue effects); the ability to collect individual traces; and the scalability challenge of deploying the tracking system, for instance, when dealing with a variety of cellular network standards and providers. Each of the above-mentioned approaches has to face these aspects. Table 1 shows how GPS, GSM and Bluetooth tracking perform with respect to these important aspects of a travel survey.

Table 1. Mobility data capture techniques with respect to issues in the context of travel surveys. Low=little issue, High=big issue

Mobility data capture techniques / Issues	Scalability	Longetivity	Individual traces	Privacy
GPS	High	High	Low	Medium
GSM (device-based)	High	Medium	Medium	Medium
GSM (aggregated network-based)	High	Low	High	Medium
Bluetooth	High	Low	Low	Medium

Some scholars work in the combination of the approaches to produce more complete spatial data (origin, route, destination) when tracking individual's routes (Kracht, 2004). However, while promising, the approach has not been able to address all the issues. In the remainder of this paper, we argue that a new type of explicitly disclosed spatio-temporal data coming from public web platforms can overcome these constraints and provide an additional insights to understand the dynamic of people in an urban space.

3. The raw data and the processing

We study photos uploaded on the popular photo-sharing platform Flickr. People use this service to share and organize photos; an option allows to add them geographical references. Each time a photo is virtually linked to a physical location, the Flickr system assigns a longitude and latitude and retrieves the time of capture from the Exchangeable Image File Format (EXIF) metadata embedded in the photo. The location provided by the user generally indicates where the photo was taken; but sometimes it denotes the photographed object. When the user provides the location of the photo, the zoom level of the map (from 8 for region/city level to the most precise 16 for street level) is recorded as an accuracy attribute, completing the spatio-temporal information.

Figure 1 describes the process of recording and collecting the data. First, tourists take photos during their trips and journeys. Later, they manually associate a position to the photos through a Flickr map interface or other external map-based services. A minority of tech savvy users has their photos implicitly annotated with a position extracted from data collected by GPS devices embedded or external to the camera. From the publicly available photos in a given area, we retrieve the coordinates, timestamp, accuracy level, and an obfuscated identifier of the owner via the Flickr API. Based on these data, as an example, a chronologically ordered set of photos gives rise to traces that reveal the movements of different individuals in space. In the figure we show as well some analysis tools we discuss later.

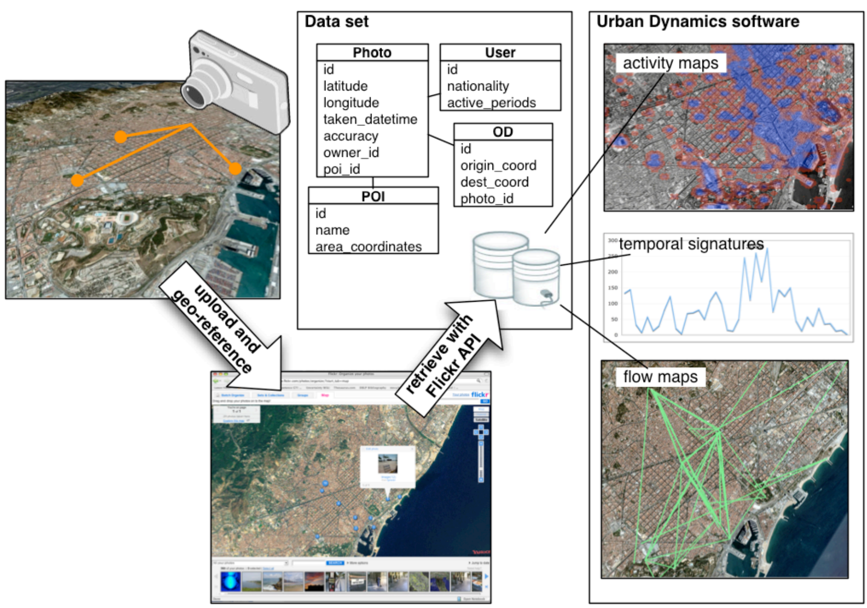

Figure 1. Data flow, from data recording, retrieving, storing to the visualizations. Photographic imagery copyright 2007 DigitalGlobe.

Our data set contains photos from the Province of Florence in Italy over a 2-year period, from November 2005 to November 2007. The timestamps extracted from the camera-generated EXIF metadata do not necessarily match the correct time. Indeed, the capturing devices might not be set with the correct time zone information, and the accuracy of the time embedded in the photo when it is taken is uncertain. However, the temporal analysis we describe later indicates that this seems to have little impact on our analyses. For example, as we consider only photos stamped in 2005, 2006 or

2007, we can assume that the user had set the camera date as its default value is rarely one of these years.

A first step of pre-processing was to separate visitors from residents of the region. To achieve that, we used the presence in the area over time as the discriminating factor. We divided the time in 30-day periods and computed the number of periods each photographer was active in the area. If a photographer took all his/her photos within 30 days, the algorithm considers him/her as a visitor, while if there is an interval greater than 30 days between two photos taken, he/she is categorized as resident. The aim of this strict threshold was to capture the real one-time tourists. Out of a population of 4280 photographers, we identified 3505 one-time visitors.

In addition, we were interested to know more about the nationalities of our photographers. Hence, we took advantage of the Flickr social function that invites (without forcing) users to provide "offline bits" on their city and country of residence. We found out that 65% (2782 out of 4280) of the users actually disclosed this information. While it is hard to predict how much of this data is truthful, the country of residence could be retrieved by automatically parsing the data in most cases. We had to assign manually a country in 11% (306/2782) of the cases, because of spelling errors or idiosyncratic names (e.g. "Big Apple" for New York).

Before going any further, let us remark that collecting and analyzing any kind of mobility data raises serious privacy issues; people are concerned about revealing the history of their whereabouts to un-trusted third party applications. We are concerned as well and our approach addresses this at two different levels. First, the users explicitly disclose the position of their photos on maps and control who gets access to their location data for our data set. Moreover, while obtaining this public information, we applied an obfuscation algorithm to lose the relationship with the identity used in Flickr. Thus, we only analyze anonymized records of digital traces publicly disclosed by individuals.

Our experience of collecting Flickr geo-referenced data provided some insights on the data at hand, which are an indicator of different aspects of their value. As of March 2007, Flickr contained more than 20 million photos linked to a physical location. Cities such as London or New York contain more that 250’000 photos and 9’000 single photographers each and growing pace of around 400 photos a day for London, and 150 a day for Barcelona. This quantitative richness might push towards an even bigger increase of publicly accessible people-generated location and time of the Flickr data set. At another level, a very specific type of people use Flickr to geographically reference their images. They are generally well travelled and technologically savvy. Therefore, we are dealing with a very specific type of tourists.

In addition, unlike the automatic capture of traces, the manual location disclosure embedded in the act of geotagging of photo provides additional qualities Positioning photo on a map is not simply adding information on its location, it is also an act of communication containing what people estimate as being relevant for themselves and others. In that sense, a specific richness of this dataset arises in the intentional weight people put in disclosing their photos. We show that they have a tendency to select the highlights of their discovery of the city and discarding the downtimes.

4. Tools used, and initial results

This section of the paper presents the geovisualizations that are produced by our tools and discusses their meanings. In the research process, we were driven by an overarching research question: what is the spatio-temporal behaviour of tourists from different nationalities, inside the Province of Florence? Flickr seemed an adequate context to extract data from, as it contains the spatial and temporal elements, as well as the nationality. However, we have to take into account the following caveats: we have already discussed the lack of temporal accuracy; second we cannot assume perfect mirroring of the Flickr spatio-temporal patterns and the actual ones, as we do not know where users have actually been between a given photo and the following one. In other words, we can only deal with approximations. With these limitations in mind, we provide an analysis of the data based on map visualizations to reveal the tourist concentration and flow within the Central Italy region and the city of Florence. Each set of maps aims at giving indications on the applicability of the collected data set to better understand the tourist dynamics within a certain area.

Our initial results bring a new perspective on two aspects related to spatial and temporal density and movements of visitors of the Province of Florence and its capital the city of Florence: (a) Characterizing the areas of the city/region where the tourists are concentrated, and (b) Revealing spatio-temporal signatures: activity by day of the week and month of the year, and days of the year. In addition, two types geovisualizations seek to understand better the flow of tourists into, out of and within the Province of Florence: (c) trajectories into and out of the area studied, (d) Patterns of flow within the Province of Florence.

4.1. The "Urban Dynamics" software

The extraction of structure, meaning and insight from large, multifaceted, spatio-temporal datasets is a challenging task that requires skills not possessed by many engaged in geovisualization (Dykes et al., 2007). Our approach takes advantage of open and freely-available resources and combines them using de facto standards often based on the extensible Markup Language (XML). We use Google Earth[15] for interactive visual synthesis of encodings generated using a combination of MySQL[16] for data storage and querying to select and aggregate, and a software developed in Java we named "Urban Dynamics" to access, process, transform, aggregate, cluster, sample, filter the raw data stored in the database and to generate outputs. The Keyhole Markup Language[17] (KML) is used to describe visual encodings and define interactions. Google Earth is used as a means of interactively visually analysing and inspecting data, through its spatial and temporal navigation tools, its access to wider contextual data, and its ability to create animations with image overlays. Figure 2 describes the data processing and multiple outputs generated by Urban Dynamics. The data of the photos are stored in a spatial matrix to perform population density analysis and in linked arrays of positions to reveal the traces left by people in their visits. In practical terms, a trace consists in a chronologically ordered set of geographically referenced photos taken by one person over one day. Is this the appropriate place to define the trace? Should it be defined earlier? These data structure

---

[15] http://earth.google.com/
[16] http://www.mysql.com/
[17] http://earth.google.com/kml/

can be divided in temporal periods to ground the base of a spatio-temporal analysis and visualization. The density values stored in the spatial matrix are employed to cluster the main areas of interest in the studied area. After their storage in the database, these areas are mapped in Google Earth with a KML file for identification and labelling. The software also generates from the matrix data heat maps of population density that can be included as an image overlay in KML files visualized in Google Earth. We describe next the spatio-temporal geovisualizations of flows and density generated with Urban Dynamics and the analyses of their results.

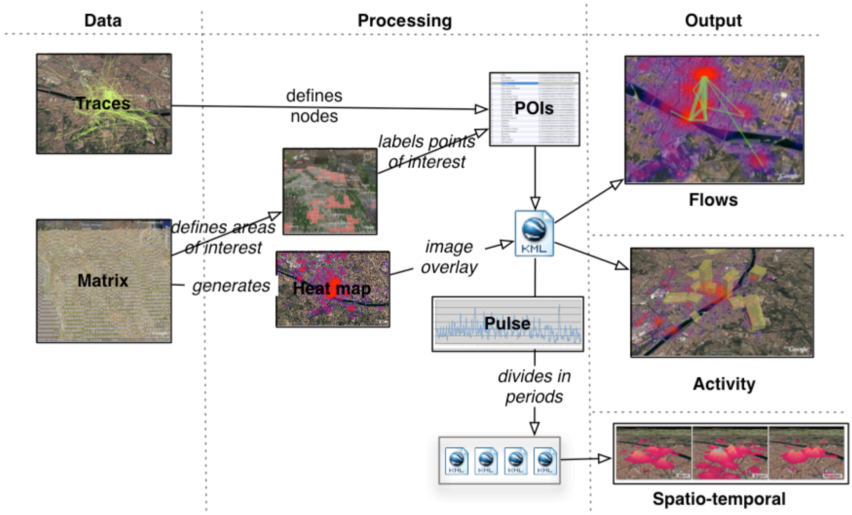

Figure 2. The Urban Dynamics software multiple data, processing and outputs. Photographic imagery copyright 2007 DigitalGlobe.

4.2. Where are the tourists concentrated?

To understand where tourists concentrate, we extracted from our dataset the latitude and longitude of the photos taken by visitors that were geotagged with a granularity more precise than the city resolution level. These data were put in a matrix covering the studied area with each cell of the matrix containing the number of photos and visitors ever present in that zone. To reveal visually the tourist concentrations, we proceeded in two steps. First, we generated from the matrix a Keyhole Markup Language (KML) document to feed it to the Geocommons[18], a geospatial data visualization platform. It produced an interactive interface with heat maps of the tourist concentrations on top of the Google Maps system (Figure 3). The results show a zoomable map of the overall tourist activity covering the northern part of Central Italy, the city of Florence and around the famous Basilica di Santa Maria del Fiore.

Figure 3. Interactive zoomable map of the overall tourist activity from the northern part of central Italy to fine-grained information on the Basilica di Santa Maria dal Fiore in Florence. Generated with GeoCommons. Photographic imagery copyright 2007 Cnes/Spot, NASA, DigitalGlobe and TerraMetrics.

These visualizations show that the main activity in the Province of Florence actually takes place in the city of Florence. There are other major points of interest in the region, such as the cities of Pisa and Siena, as well as the Mediterranean coast between La Spezia and Livorno, and the Island of Elba. Within the city, the tourists tend concentrate around the Ponte Vecchio and the Basilica di Santa Maria del Fiore. While these geovisualizations give a quick and simple overview of the presence of tourists, they do not offer a scale to understand the quantitative meaning of the colours. Therefore, as a second step, we developed an algorithm with the Processing[19] Java Library to generate heat maps for their inclusion as an additional layer in Google Earth. Next, we clustered the presence values in the matrix to define the major areas of tourist concentration. A list of 50 areas each representing a point of interest was computed and manually labelled according to their position on the map. The match of the areas with the matrix values allowed rank the major points of interest of the area studied according to the number of photos taken, the number of tourists and residents, number of photos taken by person and the likeliness to encounter

[18] http://www.geocommons.com/
[19] http://www.processing.org

residents or tourists (Figure 4). The Basilica di Santa Maria del Fiore is the most visited monument of the city followed by the famous Ponte Vecchio, the Plaza de la Signoria and Palazzo Vecchio. However, the Arco Lorena is the monument that tourists like to photograph the most (18.06 photos per tourist) compared to the Basilica di Santa Maria del Fiore that triggers 7.72 photos per tourist. Fiesole, a town in the suburbs of the city is one of the main point of interest fairly out of the tourist frenzy with a proportion of visitors of 73% compared to the 89% of the Ponte Vecchio.

Figure 4. Presence of tourists in the main areas of interest in downtown Florence. The visualization shows areas of activity (i.e. photos taken) in red and the presence of tourists with yellow polygons. The altitude of the polygons represents the number of individuals present. Photographic imagery copyright 2007 DigitalGlobe.

4.3. Temporal activity and spatio-temporal signatures

In our first attempt, we produced maps of tourist concentrations without taking into account the period when data were recorded. In this section, we generated similar maps to compare the activity in time, namely, seasons and weekends versus weekdays, etc. As differential data might be more informative, we took the "tourist pulse" of the area of study, by developing first its spatio-temporal signature. We charted the temporal signature of the number of visitors active in Figure 5, which shows the weekly, monthly and yearly pulse in 2007 with the number. Unsurprisingly, the summer months are the busiest of the year and tourist are more active on Saturdays and Sundays. A yearly vision of the presence reveals a steady pulse with peaks on the weekends.

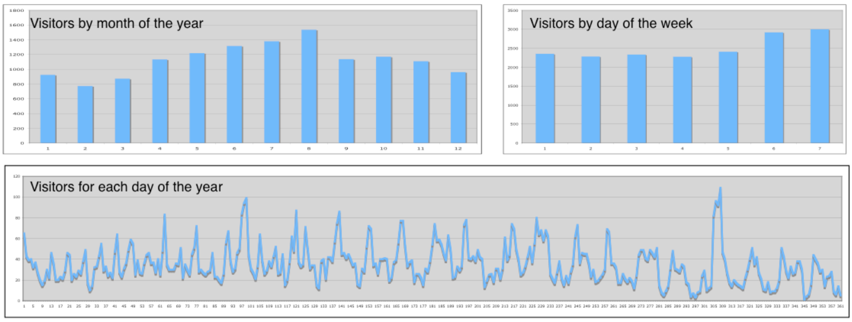

Figure 5. Pulse as the average number of visitors per each month of the year, day of the week and day of the year for 2007.

Based on the 2006 data, we produced animations of monthly activity to understand where and when was taking place the tourist activity (Figure 6). Our geovisualization adds a layer on top of a map of the Province, showing 250 x 250 cells of 20m x 12m whose colors represented the number of photos taken and visitors present. Similarly to Real-time Rome animations based on Erlang values (Reades et al., 2007), we used a 5 persons threshold to reveal the main areas of activity. That is, any cells of the matrix containing less than 5 persons were discarded. In addition we smoothed the visualization of areas of activity with an interpolation algorithm. This type of animation helped revealing the areas and monuments popular at certain seasons. The Boboli gardens, for instance, do not draw many visitors in winter while other points of interests do not lose much attractiveness.

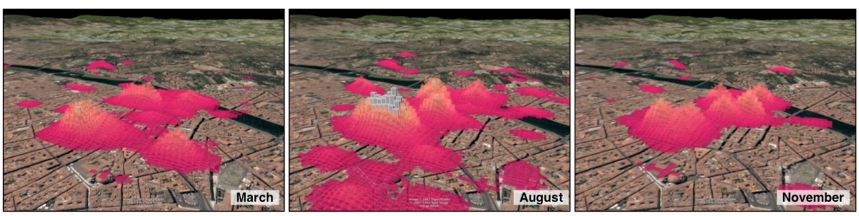

Figure 6. Screenshots of the spatio-temporal animation of the presence of tourists in downtown Florence in 2007. Photographic imagery copyright 2007 DigitalGlobe.

4.4. Inbound and outbound trajectories

As we discussed earlier, the classic survey-based hotel and museums frequentation data used by tourist authorities to know where tourists of different nationalities come from and go do not capture “day trippers”, the tourists who visit Florence but do not sleep in town. Our data brought a new perspective on the issue to understand where the visitors had been prior to entering the area and where they were heading after leaving it. We retrieved the images the 3505 visitors took prior to entering, and after leaving the area. As a result, we collected more than 1.8 million geographically referenced photos taken worldwide. Then, we recovered the inbound and outbound trajectories through the rules described in Table 2. A specific problem was to find the proper threshold in time to infer a precise origin of an inbound movement and the destination of an outbound one. The test of different thresholds of 24, 48 and 72 hours revealed that more than 83% of the inbound and outbound movements took place within 24 hours. The movements exceeding this interval were discarded, as they might not have reflected the proper origin and destination of a journey via Florence.

Table 2. Description of the algorithm to detect inbound and outbound traces

Type of trajectories	Algorithm
Inbound	Detect the position and time of the last photo before entering the area, and the position and time of the first photo after entering the area.
Outbound	Detect the position and time of the first photo after leaving the area, and the position and time of the last photo before leaving the area.

With the similar process and tools as the ones described in section 4.1. we plotted two types of geospatial visualizations to provide information on where tourists are prior to entering the city of Florence and after leaving it. The first result is an interactive zoomable heat maps that reveals density of inbound and outbound destination of a day trip in Florence. With the manual annotation of the heat maps we were able to define the 28 main areas and cities of origin and destination. Each area had a bounding box and assigned with the number of incoming and outgoing visitors computed. With this quantitative understanding of the trajectories, our software generated flow maps to offer another perspective on the movement by rendering the trajectories of tourist. They are generated from KML files of origin and destination traces loaded in the Google Earth software. For flows leading out of Florence (Figure 7), each green trace links the position of the last photo taken in Florence with the position of the first photo taken outside the city within 24 hours. Figure 7b displays through an analogous strategy, the aggregates outbound movement from the city of Florence. The comparison of inbound and outbound trajectories shows striking similarities. The most connected cities, Rome, Pisa and Venice generated a relatively equal amount of incoming and outgoing movements. Florence acts as connecting city between the north and the more southern part of Italy with Rome as the main destination.

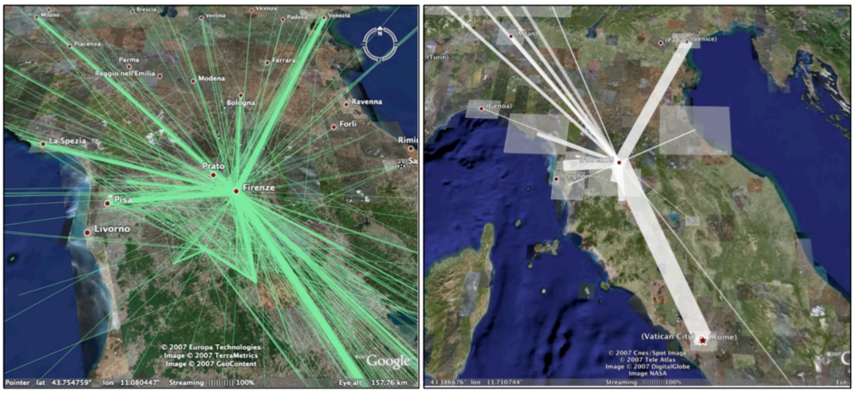

Figure 7. Outbound trajectories from the city of Florence. The map displays the individual traces in green and their aggregation in white. Photographic imagery copyright 2007 Cnes/Spot, NASA, DigitalGlobe and TerraMetrics.

4.5. Patterns of flow

In addition to revealing the origins and destinations of the tourists, the analysis of the dataset allows to gather insights on the flows within the boundaries of the northern part of Central Italy and the city of Florence. We could trace the Flickr users from the digital footprints they leave along their path. Aggregating these personal footprints and formatting them in KML reveals the travel behaviours of specific types of visitors. For instance, Figure 8 shows that tourists from the USA follow a specific graph constituted by the nodes of Florence, Siena, Pisa, Genova and Perugia. On the other hand, Italians are more adventurous in their exploration of the area. For instance it shows the popularity of the Island of Elba, an attraction not visited by American tourists.

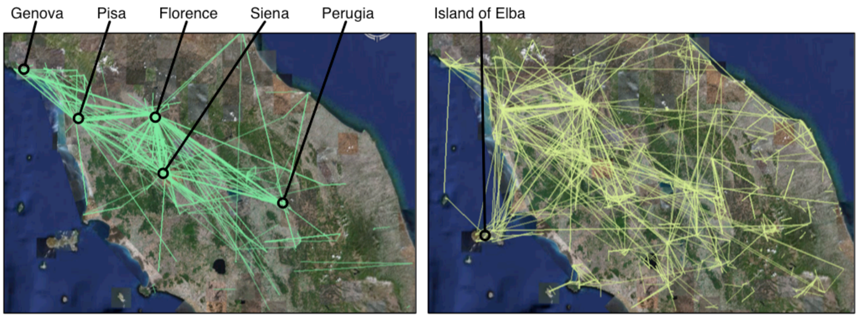

Figure 8: Movements of Americans in green compared to Italians in yellow in northern part of central Italy. The comparaison of the visualization shows the distinct was to apprehend the space. Photographic imagery copyright 2007 Cnes/Spot, NASA, DigitalGlobe and TerraMetrics.

In practice, our basic flow maps can easily become too cluttered and prevent the detection of flow patterns. As a solution, we use the main areas of interests of the Province of Florence and the city. Our visualization software matches these areas of interests with the traces left by visitors to gain a quantitative measurement of the movements between the main attractions of the area studies. Figure 9 shows the result of this process for downtown Florence. Our software generates the traces left by each visitor and aggregates them in correspondence to the main points of interests they connect. A KML file is generated with the heat map as an image overlay object and the flows between each point of attraction plotted as green lines with a weight proportional to the density of the flow. This combined vision of the density and flow of tourists shows that they consume a very limited space of the city. The tour to the unique relatively distant area of interest, the viewpoint of the Piazzale Michelangelo, seems to take place from and the most popular monument of the city, the Basilica di Santa Maria del Fiore.

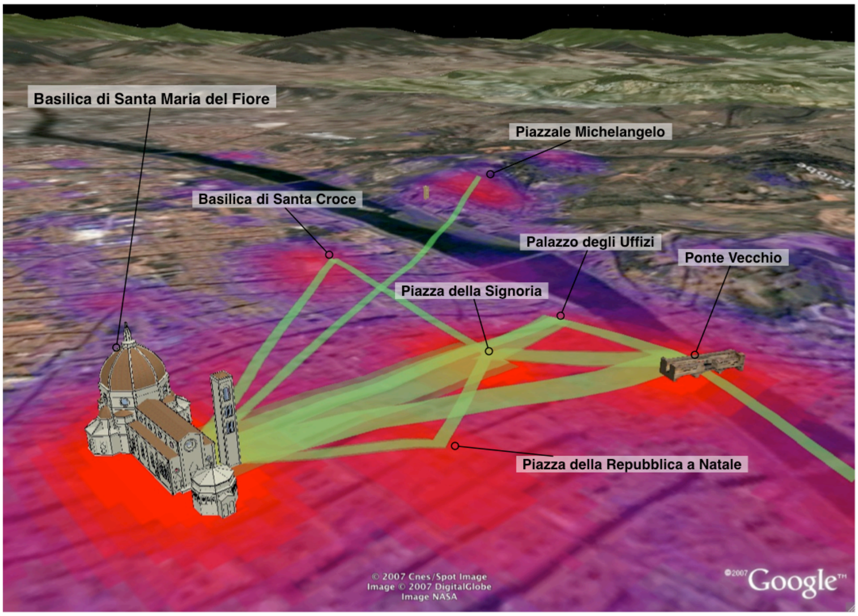

Figure 9: Downtown Florence, main areas of tourist activity (in red) and flows of visitors between them (in green). The width of the green line represents the amount of visitors who moved from one attraction to another. Photographic imagery copyright 2007 Cnes/Spot, NASA, and DigitalGlobe.

5. Conclusion and future work

The explosion in the use of captures devices (e.g. mobile phone, digital cameras) and the emergence of content sharing platforms is leading to the emergence of a wealth of publicly available user-generated geospatial data. Our case study specifically featured the value of Flickr and its geographically reference photos in the Italian Province of Florence with the goal of performing urban and mobility analysis. Our approach takes advantage of individual traces made publicly available to analyze behaviours in a urban space. Their exploratory analysis enables us to quantify by the amount of photos taken and the presence of individuals the attractiveness over time of the major points of interests of an urban space. In addition, the mapping of these data shows the flows entering, leaving and visiting a city like Florence. Not only the photos allow us to quantify the movements between attractions, they also help detecting the distinct patterns of mobility among groups of tourists of different nationalities. This type of insight is limited in most travel surveys and urban sensing infrastructure by privacy-sensitive or aggregated information.

The careful processing of the user-generated data, and the use of appropriate geovisualizations are necessary ingredients of the analyses performed. We have indicated where some improvements of the processing and the visualizations might come from. For instance, we need to find out more on the representativeness of the user of Flickr and their veracity in disclosing the photos they share. User-generated data require special attention to self-selection in the data sample. Indeed, those people who proactively upload digital information on open platforms such as Flickr are very likely to represent a tech-savvy sub-section of any given population. By collecting further data on the socio-demographics of these users, it might be possible to understand better how much the behaviour findings from research based on a self-selected sample can be generalized to a given population.

This case study could open a new perspective in urban cartography and lead to a new urban paradigm based on the analysis of publicly available people generated geo-referenced data. The explicit act of sharing this information with the ability to control and cloak the data greatly reduces privacy concerns inherent to current travel surveys techniques, as we have shown in this paper. In addition, unlike the classic automatic capture of traces, the act of geotagging a photo can be interpreted as an act of communication because people only give information they estimate as being relevant for themselves and others. In that sense, a richness of people-generated geographically referenced data relies on the specific effort people put in to disclosing the location information. Our geovisualizations show that they have a tendency to select the highlights of the their discovery of the city and discard the downsides.

In the future, similar types of spatially anchored user-generated content might surface to become relevant for travel, mobility and urban studies. Sources might range from implicit data from the usage of radio-frequency networks (GPS, GSM, WiFi, Bluetooth) to more explicit information contained in geospatial web applications (e.g. geo-referencing in Flickr), and the emerging social applications based on the disclosure of presence and location information. Researchers, urban planners, local authorities, and others might consider the aggregate analysis of these different channels.

As part of further work, we consider several extensions to the promising results presented in this paper. First we aim at correlating our dataset with other spatio-temporal data such as GSM network usage, hotel and attractions surveys. Second, we believe that the recording of such data could be used to inform the design and deployment of location-based services to enhance the tourist experience. So far location-aware applications have tended to concentrate on using a mobile carrier's immediate geographic location. We believe that using a position history to tailor results from requests for information should enhance them (Mountain and Raper, 2001). This work shows that there might be potential in taking advantage of the digital traces people constantly leave behind them to, for instance, reveal the temporal character of a space, its attractiveness among a certain group of people, and its level of connectivity with other spaces.

Acknowledgements

The results reported in this paper are part of a broader research undertaken in the Wireless City, Florence and Beyond project. We would like to thank the authorities of the Province of Florence for their support. Also, we are indebted to many people at the Massachusetts Institute of Technology and the Universitat Pompeu Fabra for providing extremely stimulating research environments and for their generous feedback. In particular, thanks to Assaf Biderman, Francisco Calabrese, Nicolas Nova, Bernd Resch and Toni Navarrete for letting us pick their brains. Of course, any shortcomings are our sole responsibility.

References

Ahas, R., Aasa, A., Silm, S., Tiru, M. 2007. Mobile positioning data in tourism studies and monitoring: case study in Tartu, Estonia. In: Sigala, M., Mich, L., Murphy, J. (Eds.), *Springer Computer Science: Information and Communication Technologies in Tourism*, ISBN: 978-3-211-69564-7, pp. 119-128.

Ahern, S., Naaman, M., Nair, R., and Yang, J. H. 2007. World explorer: visualizing aggregate data from unstructured text in geo-referenced collections. In *JCDL '07: Proceedings of the 2007 conference on Digital libraries*, pages 1–10, New York, NY, USA. ACM Press.

Asakura, Y. and Iryob, T. 2007. Analysis of tourist behaviour based on the tracking data collected using a mobile communication instrument. *Transportation Research Part A: Policy and Practice*, 41(7):684–690.

Ashbrook, D. and Starner, T. 2002. Learning significant locations and predicting user movement with gps. In *ISWC '02: Proceedings of the 6th IEEE International Symposium on Wearable Computers*, page 101, Washington, DC, USA. IEEE Computer Society.

Dykes, J., Slingsby, A., and Clarke, K. 2007. Interactive visual exploration of a large spatio-temporal dataset: Reflections on a geovisualization mashup. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1176–1183.

Eagle, N. and Pentland, A. S. 2006. Reality mining: sensing complex social systems. *Personal Ubiquitous Comput*., 10(4):255–268.

Froehlich, J., Chen, M. Y., Smith, I. E., and Potter, F. (2006). Voting with your feet: An investigative study of the relationship between place visit behavior and preference. In *Ubicomp*, pages 333–350.

Gutman, M. and Stern, P., editors 2007. Putting People on the Map: Protecting Confidentiality with Linked Social-Spatial Data. *National Academies Press*.

Hazas, M., Scott, J., and Krumm, J. 2004. Location-aware computing comes of age. *IEEE Computer*, 37(2):95–97.

Kracht, M. 2004. Tracking and interviewing individuals with gps and gsm technology on mobile electronic devices. In *Seventh International Conference on Travel Survey Methods*.

Krumm, J. and Horvitz, E. 2006. Predestination: Inferring destinations from partial trajectories. In *Ubicomp*, pages 243–260.

Mountain, D. and Raper, J. 2001. Modelling human spatio-temporal behaviour: a challenge for location-based services. In *6th Internat. Conference on GeoComputation*. University of Queensland, Brisbane, Australia.

O'Neill, E., Kostakos, V., Kindberg, T., gen. Schieck, A. F., Penn, A., Fraser, D. S., and Jones, T. 2006. Instrumenting the city: Developing methods for observing and understanding the digital cityscape. In *Ubicomp*, pages 315–332.

Ratti, C., Pulselli, R. M., Williams, S., and Frenchman, D. 2006. Mobile landscapes: Using location data from cell-phones for urban analysis. *Environment and Planning B: Planning and Design*, 33(5):727 – 748.

Reades, J., Calabrese, F., Sevtsuk, A., and Ratti, C. 2007. Cellular census: Explorations in urban data collection. *IEEE Pervasive Computing*, 6(3):30–38.

Rattenbury, T., Good, N., and Naaman, M. 2007. Towards automatic extraction of event and place semantics from flickr tags. In *SIGIR '07: Proceedings of the 30th annual international ACM SIGIR conference on Research and development in information retrieval*, pages 103–110, New York, NY, USA. ACM Press.

Schoenfelder, S., Axhausen, K., Antille, N., and Bierlaire, M. 2002. Exploring the potentials of automatically collected gps data for travel behaviour analysis - a swedish data source. In Möltgen, J. and Wytzisk, A., editors, *GI-Technologien für Verkehr und Logistik*, number 13 in IfGIprints, pages 155–179. Institut für Geoinformatik, Universität Münster.

Snavely, N., Seitz, S. M., and Szeliski, R. 2006. Photo tourism: exploring photo collections in 3d. *ACM Trans. Graph.*, 25(3):835–846.

Sohn, T., Varshavsky, A., LaMarca, A., Chen, M. Y., Choudhury, T., Smith, I., Consolvo, S., Hightower, J., Griswold, W. G., and de Lara, E. 2006. Mobility detection using everyday gsm traces. In *Ubicomp*, pages 212–224.

Stopher, P., Bullock, P., and Jiang, Q. 2003. Visualising trips and travel characteristics from gps data. *Road & Transport Research*, 12(2):3–14.

Torniai, C., Battle, S., and Cayzer, S. 2007. Sharing, discovering and browsing geotagged pictures on the web. Technical report, HP Labs.

Wermuth, M., Sommer, C., and Kreitz, M. 2003. *Impact of New Technologies in Travel Surveys*, chapter 27, pages 455–482. Pergamon, Oxford.

Wolf, J. 2004. Applications of new technologies in travel surveys. In *7th International Conference on Travel Survey Methods, Costa Rica*.

Wolf, J., Guensler, R., and Bachman, W. 2001. Elimination of the travel diary: experiment to derive trip purpose from global positioning system travel data. *Transportation Research Record*, (1768):125–134.

Digital footprinting: uncovering the presence and movements of tourists from user-generated content

Fabien Girardin[a,b], Francesco Calabrese[b], Filippo Dal Fiore[b], Carlo Ratti[b] and Josep Blat[a]

[a]Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain
[b]Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, USA

Abstract. In recent years, the large deployment of mobile devices has led to a massive increase in the volume of records of where people have been and when they were there. The analysis of these spatio-temporal data can supply high-level human behavior information valuable to social scientists, urban planners and local authorities. This paper explores this hypothesis by reporting on new information revealed by this pervasive user-generated content. We present novel techniques, methods and tools we have been developing to explore the significance of these new types of data. In a case study of Rome, Italy, we showcase the ability to uncover the presence and movements of tourists from geo-referenced photos they explicitly make public, as well as from network data implicitly generated by users of mobile phones.

1. Introduction

Nowadays every click of every move of every user who interacts with any software may be gathered in a database and submitted to a second-degree data-mining operation. Along with the growing of ubiquity of mobile technologies, the logs produced have helped to create and define new methods of observing, recording, and analyzing the city and its human dynamics [1]. In effect, these personal devices create a vast, geographically-aware sensor web [2], which uses the accumulation of tracks to reveal both individual and social behaviors with unprecedented detail [3]. The low cost and high availability of these ‘digital footprints’ will challenge the social sciences, which have never before had access to the volumes of data used in the natural sciences [4], but the benefits to fields where an in-depth understanding of large group behavior could be equally great.

Accordingly, this paper illustrates the potential of user-generated electronic trails to reveal – remotely – the presence and movement of visitors in a city. We anticipate that the validation of these trails with respect to existing surveys may lead to an improved understanding of several aspects of urban mobility and travel. We therefore present several novel data collection techniques, analytical methods, and visualization tools that we have been developing to uncover these dynamics in the city. While the nature of digital footprints renders the information derived both more credible and reliable, we must further consider how to validate this pervasively user-generated content.

In previous work, we showed that explicitly disclosed spatio-temporal data from open platforms provide novel insights on the dynamics of visitors in an urban space [5]. Understanding population dynamics by type, by neighborhood, or by region would enable the provision of customized services (or advertising) as well as the accurate timing of urban service provision, such as the scheduling of monument opening times based on the presence of tourists, based on daily, weekly, or monthly demand. In general, more synchronous management of service infrastructures clearly could play a particularly important in tourism management.

2. Working with Digital Footprints

Visitors to a city have many ways of leaving voluntary or involuntary electronic trails: prior to their visits tourists generate server log entries when they consult digital maps [6] or travel web sites; during their visit they leave traces on wireless networks whenever they use their mobile phones; and after their visit they may add online reviews and photos. Broadly speaking then, there are two types of footprint: active and passive. Passive tracks are left through interaction with infrastructure, such as the mobile phone network, that produces entries in locational logs, while active prints come from the users themselves when they expose locational data in photos, messages, and sensor measurements.

In this paper, we consider two types of digital traces from the city of Rome, Italy: geo-referenced photos made publicly available on through the photo-sharing web site Flickr[20], and aggregate records of wireless network events generated by mobile phone users making calls and sending text messages on the Telecom Italia Mobile (TIM) system.

2.1. Explicit footprints: georeferenced photos

People using the Flickr service to share and organize photos also have the option to add geographical attributes. Each time a photo is anchored to a physical location, Flickr assigns longitude and latitude values together with an accuracy attribute derived from the zoom level of the map in use to position the photos. So photos positioned on a map when the user is zoomed in at the street level receive a higher accuracy estimate than ones positioned when the user had pulled back in the online map view. The system also adds metadata embedded by the camera into the image using the Exchangeable Image File Format (EXIF) information, completing the spatio-temporal information.

Flickr also provides a public Application Programming Interface (API) that enables anyone to query their public data store for photos. We elected to analyze three years of data – from November 2004 to November 2007 – for the city of Rome since it is a very popular and highly photographed tourist destination. For the 3-year period of interest, we were able to extract 144,501 geo-referenced photos that had been uploaded by 6,019 different users. For each of these publicly available photos, we retrieved the geographical coordinates, timestamp, accuracy level, and an obfuscated identifier of the owner.

Since we were particularly interested in the behavior of tourists in Rome, we separated the photographers into two groups based on their presence in the city over time. Discriminating between locals and visitors required dividing the study period into 30-day blocks: if a photographer took all his or her photos within a period of thirty days, the algorithm considered them to be a visitor, but if they uploaded photographs at intervals of more than 30 days then they

---

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

would be categorized as a resident. From our population of 6,019 photographers, 4,719 were classed as one-time visitors.

To find out more about the nature of our photographers, we took advantage of a social function in Flickr that invites users to voluntarily provide additional information about themselves such as their city and country of residence. In some cases, because of spelling errors or user idiosyncrasies – such as using “The Big Apple” to mean New York City – we were forced to manually process the city or country information. However, after cleaning we found that 59% of the users had disclosed meaningful origin information. They break into several main populations: 991 Italians, 1171 other Europeans, 807 North Americans, 104 South Americans, 71 Asians, and 70 from Australia and New-Zealand.

2.2. Implicit footprints: wireless network usage

Previous research has shown the wide diffusion of mobile phones and the widespread coverage of mobile phone wireless networks in urban areas make these technologies very interesting as means to identify and track both groups and individuals [7, 8]. Our collaboration with TIM took advantage of new a system called LocHNESs (Localizing & Handling Network Event Systems), which is a software platform that localizes and stores user-generated events as they occur on the mobile network. Calls in progress, SMS transmissions, and call handovers are all captured through external probes that localize and collate incoming messages before transmitting the results to LocHNESs. The messages are then aggregated to produce raster-format maps of the distribution of users. A detailed introduction to the platform can be found in Calabrese et al [9].

TIM installed the LocHNESs platform and related probes on a set of Base Station Controllers (BSC) located in the northeast quadrant of the city, covering an area of approximately 100Km^2. The system permits users to be reliably localized to within an area of 250 by 250 m^2 and then assigned to the corresponding grid reference. LocHNESs divided the users into two groups – Italians and foreigners – based on the country code information embedded in their International Mobile Subscriber Identity (IMSI) number. Over a period of three months, timed to coincide with the Venice

Biennale from September to November 2006, the system calculated these attributes every five minutes and transmitted the results to servers at the Massachusetts Institute of Technology (MIT).

2.3. Processing and Visualization

Dykes et al. [10] suggest that the large volumes of data coming from these types of sources can only be interpreted through geovisualization, which is to say that after collection, mapping and visualization is critical to interpreting and explaining user behaviors. We elected to use Google Earth to support visual synthesis and our preliminary investigation of digital traces. Accordingly, data collected by the LocHNESs platform and from the Flickr service was stored on a MySQL server, enabling us to flexibly query and aggregate the data further as required. Using software developed in-house, we then exported the aggregate results in a format compatible with Google Earth for interactive visual exploration. Precise digital satellite imagery from Telespazio was added as image overlay. The application of these techniques and tools to process digital footprints allows us to uncover the presence of crowds, the patterns of movement over time, and to perform a comparison of user behaviors to generate new hypotheses.

3. Analysis of Digital Footprints

3.1. Spatial presence

To map the spatial distribution of users, data is stored in a matrix covering the entire study area. Each cell in the matrix includes data about the number of photos taken, the number of photographers present, and the number of phone calls made by foreigners over a given period of time. The geovisualization shown in Figure reveals the main areas of tourist activity in part of central Rome over the 3-month period of September to November 2006.
The presence of photographers is pictured in left and areas of heavy mobile phone usage by foreigners are depicted on the right. The union between visiting photographers and foreign mobile phone customers quickly uncovers the area’s major visitor-attractions such as the Coliseum and the main train station next to Piazza della Repubblica. Intriguingly, it appears that the Coliseum attracts the photographers in their sightseeing activity while foreign mobile

phone users, typically on the move, tend to be active around the train station.

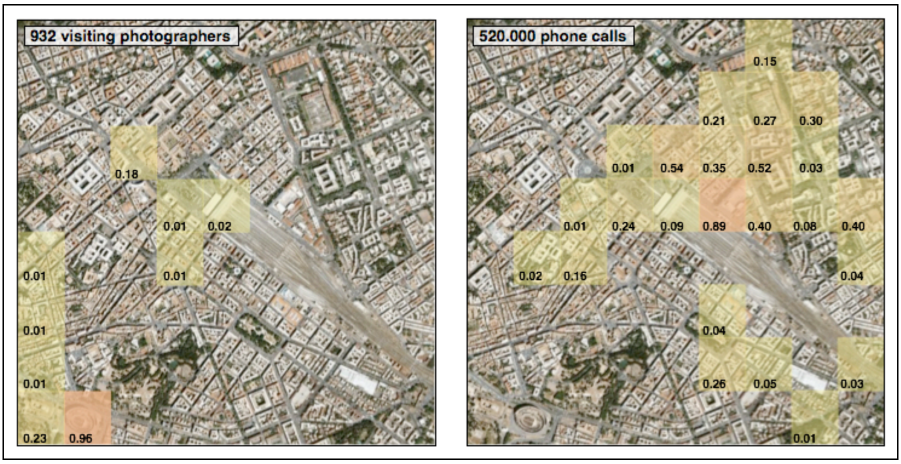

Figure 1. Geovisualizations of the presence of 932 tourist photographers (left) and 520 000 phone calls from foreign mobile phones (right) in the Coliseum-Piazza della Repubblica area from September to November 2006. Both type of data cover the train station area in the proximity of the Piazza della Republica. The values in each cell are normalized.

3.2. Temporal presence

Turning to the temporal patterns obtained from the digital traces, we compared the number of photographers and the volume of phone activity for each day of the week over the 3-month study period. Figure shows the difference between the average weekly distribution of phone calls made by visitors and the presence of visiting photographers in the areas around the Coliseum and Piazza della Repubblica. The histograms show the normalized variation between the average number of calls and the average number of photographs for each day of the week, and the average amount for the whole week.

The resulting temporal signatures for the Coliseum area show related trends for both data sets, with higher activity over the weekend than on weekdays. However, the Piazza della Repubblica area reveals a markedly different pattern: photographers, though fewer in number than at the Coliseum, also tend to be active on the weekend, whereas the foreign mobile phone users are much more active during the weekdays.

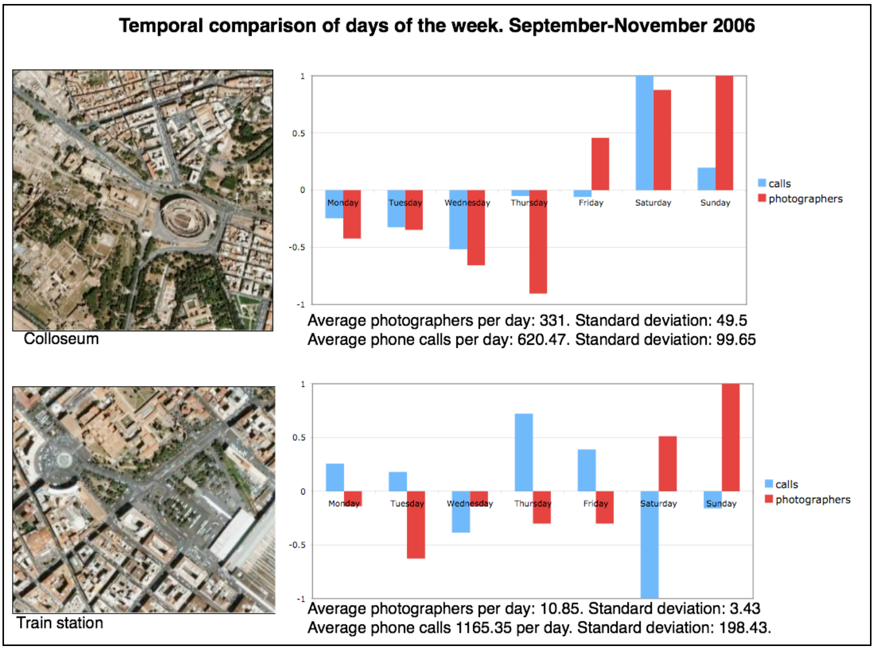

Figure 2. Comparison of the temporal signature of foreigners phone activity and number of tourist photographers. It reveals similar patterns of low below average activity during the week days and a rise of presence over the weekend at the Coliseum. In opposition, the temporal signature of the train station shows a higher presence of foreigners calling from their mobile phones during the week, while photographers indicate a reverse pattern and increased presence over the weekend.

These temporal signatures provide further evidences to the different types of presence that occur at the tourist points of interest. It can be further hypothesized that the Coliseum attracts sightseeing (i.e. photographers) activities over the weekend and the neighborhood of the train station provides facilities for visitors on the move (e.g. people on business trips) during the weekdays.

3.3. Desire lines from digital traces

The study of digital footprints also enables us to uncover the digital ‘desire lines’ embodied in people’s paths through the city. Based on the time stamp and location of photos, our software organizes the images chronologically in order to reconstruct the movement of the photographers. More precisely, we start by revealing the most active areas obtained by spatial clustering of the data[21]. Next, we aggregate these individual paths to generate desire lines that capture the sequential preferences of visitors. The location of each user activity (i.e. photo) is checked to see if it is contained in a cluster, and in the case of a match, the point is added to the trace generated by the owner of the photo. This process produces multiple directed graphs that support better quantitative analysis, enabling us to obtain the number of sites visited by season, the most visited and photographed points of interests, as well as where do photographers start and end their journeys.

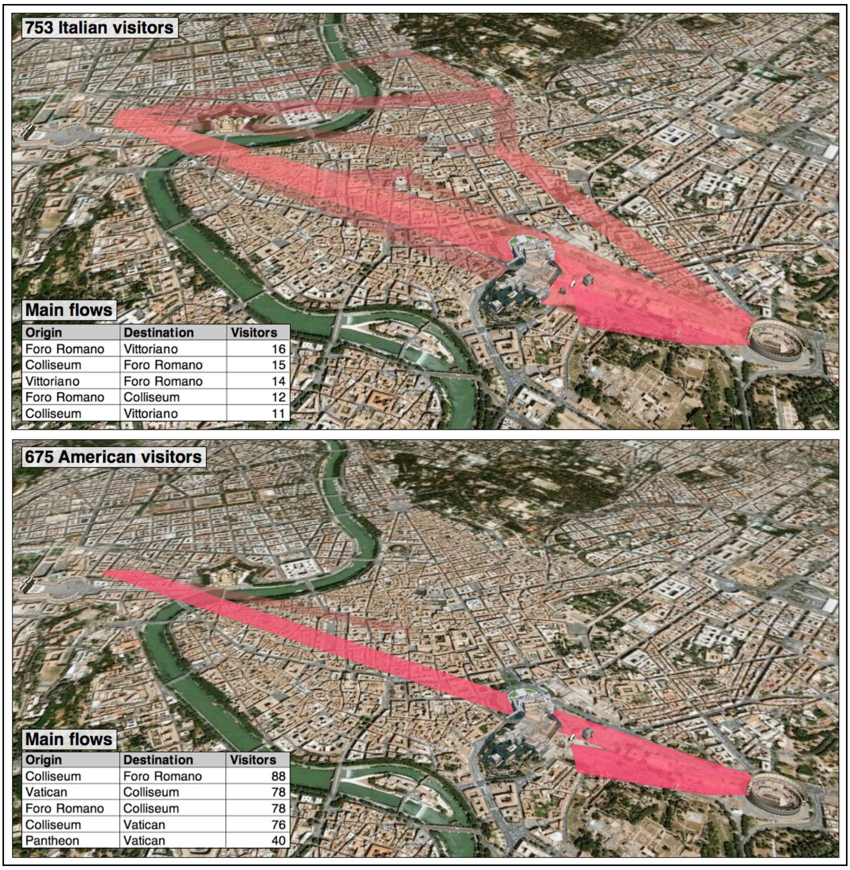

Figure 3. Geovisualiation of the main paths taken by photographers between points of interests of the city. Significantly, the 753 visiting Italian photographers (top) are active across many areas of the city, while the 675 American visitors

[21] Direct aggregation of the traces was not providing results easy to visualise and analyze.

stay on a narrow desire line between Vatican, the Forum, and the Coliseum. Note that different scales apply for each geovisualization.

Formatting this data according to the open Keyhole Markup Language[22] standard enables us to import the data into Google Earth to explore the traveling behaviors of specific types of visitors. The resulting visualization in Figure suggests the main points of interest in the city as a whole. Building asymmetric matrices of the number of photographers who moved from one point of interest 'x' to another point of interest 'y' reveals the predominant sequence of site visits. In addition, queries can be based on the nationality of the users, the number of days of activity in the city, the number of photos taken, and areas visited during a trip.

3.4. Semantic description

Previous work has demonstrated that spatially- and temporally-annotated material available on the Web can be used to extract "place" and "event" related semantic information [11]. In a similar vein, we analyzed the tags associated with the user-originating photos to reveal clues of people's perception of their environment and the semantics of their perspective of urban space. For instance, the word "ruins" is one of the most-used tags to describe photos in Rome. Mapping the distribution of this tag for 2,866 photos uncovers the most ancient and 'decayed' part of the city: the Coliseum and the Forum (Figure).

[22] http://www.opengeospatial.org/standards/kml/

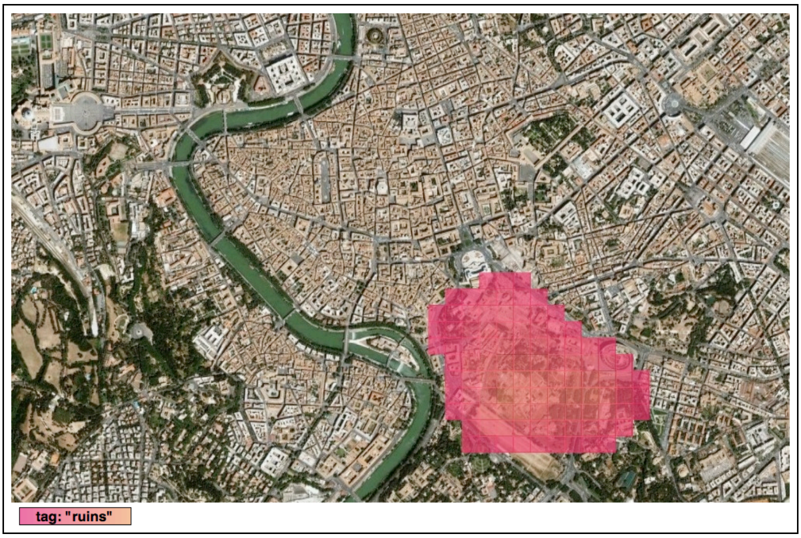

Figure 4. Geovisualization of the areas defined by the position of the 2886 photos with the tag "ruins" uploaded by 260 photographers. It reveals the Coliseum and Forum areas known for their multitude ancient ruins.

4. The significance of user-generated data

These aggregate spatio-temporal records seem to lead to an improved understanding of different aspects of mobility and travel. Although the results are still fairly coarse, we have clearly shown the potential for geographically-referenced digital footprints to reveal patterns of mobility and preference amongst different visitor groups. However, in the context of our study, traditional methods such hotel occupancy and museum surveys to observe and quantify the presence and movements of visitors would help us to better define the usefulness of pervasive user-generated content. Fortunately, the Rome Tourism office supplied us with monthly ticket receipts for the Coliseum in 2006.

Figure compares sales figures with the mobile usage and photographic activity. Ticket receipts show that there are slightly more Coliseum visitors in October than September, with a major drop in attendance during November. This pattern matches the activity of foreign-registered mobile phones in the area, but does not coincide with the activity of photographers. We hypothesize that these discrepancies arise from the fact that the datasets are capturing the activity of different sets of visitors: one set of data is generated by visitors paying to see an attraction, another by mobile service customers wealthy enough to pay international roaming charges, and the third by a technology-savvy community of people who are familiar with digital photography, and mapping and social networking software. Due to the large difference in the nature of the activity producing the data that we compare, it might be that correlating with user-generated content does not reinforce existing tourism and travel knowledge, but reveals new dimensions of user behavior.

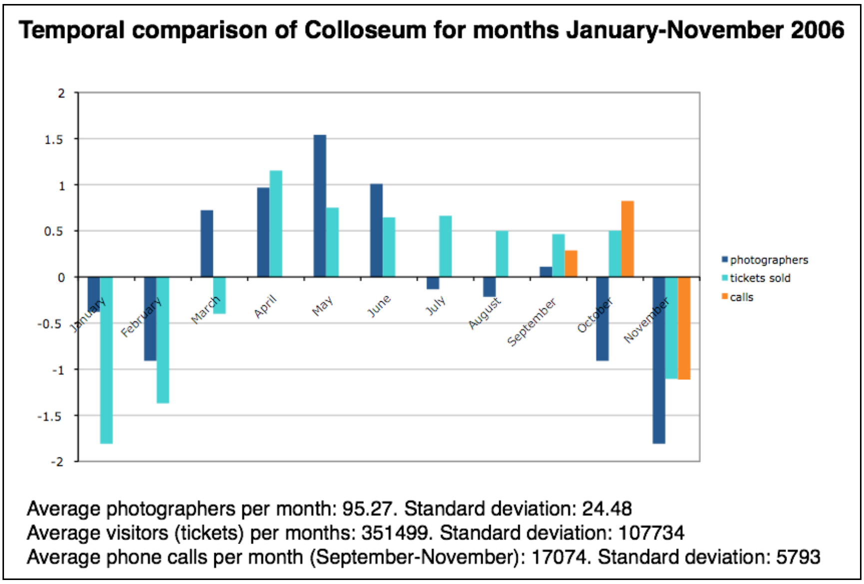

Figure 5. Comparison of the presence of visitors to the Coliseum area between January and November of 2006 using the number of tickets sold, number of calls made, and number of photographers active in the zone. The values represent the variations from the monthly average, scaled by the standard deviation.

5. Challenges in user-generated datasets

The analysis of user-generated content does not come without challenges, particularly when dealing with data quality and privacy issues.

5.1. Data quality issues

Our data processing techniques have tried account for the fluctuating quality of user-generated data, which can substantially impede our ability to generate accurate information. For instance, the timestamps extracted from the camera-generated EXIF metadata do not necessarily match the real time at which a photo was taken – the user must not only have set the clock on their camera to the local time, but they must take the time to set the clock in the first place. User-generated data points can also be apparently idiosyncratic and, for instance, indicate not the point where photo was taken but the location of the photographed object.

The inclusion of mobile phone data introduces challenging scale issues since the resolution of the phone and photo datasets vary substantially. Correlation with ticket sales from the Coliseum also fails to account for the fact that users can easily photograph the arena or make a call from the vicinity of the monument without bothering to pay the entry fee. Challenges also arise from the fact that only phone activity handled by a subset of BSCs in Rome were monitored, leading to the risk of "border effects", where calls near the border of a monitored area may be handled by other BSCs and thus not counted by the LocHNESs platform. This last consideration applies in particular to areas to the south west of the Coliseum (see also Figure).

5.2. Privacy issues

The use of photograph and mobile data can also be expected to raise privacy and ethical concerns related to collecting data without the individual's consent. However, our approach addresses these concerns on two levels: first, our photography dataset includes only information that users explicitly disclose on an open platform; and second, all data is aggregated in a way that removes all traces of the invidiaul. On the Flickr service users have direct control over who can access their locational data, but we supplemented this by applying an obfuscation algorithm to erase the relationship with the web identity of the individual and their digital trails. Thus, we could only analyze anonymous records of information already publicly disclosed by individuals.

Collection and analysis of aggregate network usage data fully-complied with the 2002 Directive of the European Parliament and Council on privacy. Data was only reported to us in aggregate, and so we received no data about an individual's identity or trajectory. In effect, we could only count the total number of people – either

Italian or foreign – that used a mobile phone at a given point in the city and at a given moment. Individual users could not in any way be identified based on the data that we collected and analyzed, and consequently we avoided the significant privacy issues that have been raised by other methodologies [8].

6. Discussion

The explosion in the use of capture and communication devices (e.g. mobile phones, digital cameras) and the introduction of content-sharing platforms has led to the emergence of a wealth of georeferenced-data. This user-generated content provides new opportunities for urban studies and the social sciences to understand the behavior of visitors and residents in an urban context. From a methodological perspective, the data we have analyzed in this paper has a clear advantage over more traditional location data obtained rather through controlled studies where subjects carried sensors and were thus aware of being tracked. Although we could not determine the sample used, our mobile phone data covers the usage habits of more than one million people and thus represents a step-change in the scale of localizable data collection efforts.

These collection methods also contain several important potential advantages over other pervasive tracking systems. Solutions that require people to carry a separate GPS-enabled device not only remind users that their movements are being followed – which might encourage them to pursue 'high-brow' activities during their visit – but also the tracking solutions that persons must carry generate fatigue effects and do not always function well in urban areas because of signal multipath and urban canyon obstructions. The alternative of a distributed, but fixed web of sensors entails onerous maintenance and data transmission costs. These issues strongly suggest that the research community should investigate and evaluate the use of these new data types as well as considering approaches that do not rely on the deployment of ad-hoc and costly infrastructures.

This paper therefore seeks to illustrate the value of explicitly-disclosed geographically-referenced photos and implicitly-generated records of mobile phone network usage. We used user-originated digital footprints to uncover some new aspects of the presence and movement of tourists during their visit to Rome. And we introduced several novel tools and techniques for this analysis, although these results demonstrate that further development is required in order to validate our observations and to lead to new insights into factors such as the temporal usage-signature of a space, its attractiveness to different groups of people, and the degree of similarity to usage of other spaces.

The explicit character of photo geo-tagging and manual disclosure to the world also provides additional dimensions of interest: positioning a photo on a map is not simply adding information about its location; it is an act of communication which embodies locations, times, and experiences that individuals consider to be relevant to themselves and others. There is a very real richness to the 'intentional weight' that people attach to disclosing their photos, and the results clearly show that Flickr users have a tendency to point out the highlights of their visit to the city while skipping over the lowlights of their trip.

However, our analysis and visualization are meant to complement, not replace, traditional surveys and other means of data collection. In the pre-digital age tourism officials could know how many visitors spent a night in a hotel, but now we can also use feedback mechanisms on public web sites to estimate how much they enjoyed their stay. Similarly, we could know how many tourists visited a given attraction; but now we can also know infer their experience of it through act of uploading a photography and the semantics of their description of it. Direct observation enables us to know the number of tourists in an area; but through the mobile phone network we can know their nationalities.

The shortcomings of single-site ticket sales as a correlating dataset requires us to pursue alternate strategies for relating our mobile and photographic data to real-world activity with traditional surveys. An additional research avenue is the understanding of the circumstances under which users tag their content with a street address or when they are tagged to a larger region. An initial analysis of our Flickr dataset suggests that the 123 German users tended to provide more accurate locational information than their 175 Spanish counterparts.

The results of further analysis may reveal distinct profiles of geo-referencing and geo-tagging photos. These profiles might be based on culture or nationality, the type of tourist in terms of their length of stay or familiarity with the city, their level of technical expertise or spatial orientation ability, an the type of task or type of environment visited. Other questions that should be considered relate to the types of situations during which users are more or less likely to use their mobile devices for data generation. Answers to these types of questions should allow us to define better the meaning of the data and to explore further their potential usage in social sciences and urban studies.

Acknowledgments

We would like to thank Barcelona Media, Telecom Italia for their support and Telespazio for their satellite digital imagery. Also, we are indebted to many people at the Massachusetts Institute of Technology and the Universitat Pompeu Fabra for providing extremely stimulating research environments and for their generous feedback. In particular, thanks to Assaf Biderman, Liang Liu, Nicolas Nova, Jon Reades and Andrea Vaccari for letting us pick their brains. Of course, any shortcomings are our sole responsibility.

References

1. O'Neill, E., Kostakos, V., Kindberg, T., gen. Schieck, A. F., Penn, A., Fraser, D. S., and Jones, T. Instrumenting the city: Developing methods for observing and understanding the digital cityscape. In *Ubicomp* (2006), pp. 315–332.

2. Goodchild, M. F. (2007). Citizens as voluntary sensors: Spatial data infrastructure in the world of web 2.0. *International Journal of Spatial Data Infrastructures Research*, 2:24–32.

3. Eagle, N. and Pentland, A. S. (2006). Reality mining: sensing complex social systems. *Personal Ubiquitous Comput.*, 10(4):255–268.

4. Latour, B. (2007). Beware, your imagination leaves digital traces, Column for Times Higher Education Supplement, 6th of April 2007. http:// www.bruno-latour.fr/poparticles/poparticle/P-129-THES-GB.doc

5. Girardin, F., Dal Fiore, F., Blat, J., and Ratti, C. (2007). Understanding of tourist dynamics from explicitly disclosed location information. In The 4th International Symposium on LBS &

TeleCartography.

6. Fisher, D. Hotmap: Looking at geographic attention. *IEEE Trans. Vis. Comput. Graph. 13*, 6 (2007), 1184–1191.
7. Ratti, C., Pulselli, R. M., Williams, S., and Frenchman, D. (2006). Mobile landscapes: Using location data from cell-phones for urban analysis. *Environment and Planning B: Planning and Design*, 33(5):727 – 748.
8. González, M., C. Hidalgo, and A Barabási (2008), "Understanding individual human mobility patterns", *Nature*, Vol.453, pp.779-782
9. Calabrese, F., Ratti, C., Real Time Rome. *Networks and Communication Studies*, vol. 20, nos. 3 & 4, (2006), pp. 247–258.
10. Dykes, J., Slingsby, A., and Clarke, K. (2007). Interactive visual exploration of a large spatio-temporal dataset: Reflections on a geovisualization mashup. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1176–1183.
11. Rattenbury, T., Good, N., and Naaman, M. (2007). Towards automatic extraction of event and place semantics from flickr tags. In SIGIR '07: Proceedings of the 30th annual international ACM SIGIR conference on Research and development in information retrieval, pages 103–110, New York, NY, USA. ACM Press.

6. Digital footprints as evidences of urban attractiveness

The previous case study (Chapter 5) demonstrated that the analysis of the digital footprints people leave behind them seems to lead to an improved understanding of different aspects of mobility, travel and tourism. For instance, information about who populates different parts of the city at different times can lead to the provision of customized services, alternative narrative of urban public spaces (Townsend, 2008) and more synchronous management of service infrastructure. In this case study that took place in summer 2008 around the New York City Waterfall public exhibit, we explore further the characteristics of explicit (georeferenced photos) and implicit (aggregated cellular network traffic data) digital footprints to define indicators that measure the evolution of urban attractiveness.

The proposition of indicators that help to compare the evolution of the attractiveness and popularity of points of interests demanded the development of technique to map the relative density of digital footprints to the urban space. It implied the creation of a radio map based on a propagation model and an interpolation model of network activity to map network statistics with wireless coverage areas to the closest fidelity to ground truth as possible. This effort of precision was particularly necessary because the study took place on a neighbourhood scale. This work allowed mapping the spatial distribution of locals and visitors and comparing the evolution of the presence of digital footprints as evidences of the positive impact of the New York City Waterfalls on the attractiveness of the waterfront.

We present this case study with the following paper:

Girardin, F., Vaccari, A., Gerber, A., Biderman, A., and Ratti, C. (2009). Quantifying urban attractiveness from the distribution and density of digital footprints. *International Journal of Spatial Data Infrastructure Research*, 4.

Quantifying urban attractiveness from the distribution and density of digital footprints

Fabien Girardin[1,3], Andrea Vaccari[1], Alexandre Gerber[2], Assaf Biderman[1], Carlo Ratti[1]

[1]Massachusetts Institute of Technology, Cambridge, MA, USA
{fabieng, avaccari, abider, ratti} @ mit.edu
[2]AT&T Labs-Research, Florham Park, NJ, USA
gerber@research.att.com
[3]Barcelona Media, Barcelona, Spain

Abstract. In the past, sensors networks in cities have been limited to fixed sensors, embedded in particular locations, under centralised control. Today, new applications can leverage wireless devices and use them as sensors to develop aggregated information. In this paper, we show that the emerging patterns unveiled through the analysis of large sets of aggregated digital footprints can provide novel insights into how people experience the city and into some of the drives behind these emerging patterns. This information has uses for local authorities, researchers, as well as service providers such as mobile network operators. To explore this capacity for quantifying urban attractiveness, we performed a case study using the distribution and density of digital footprints in the area of the New York City Waterfalls, a public art project of four man-made waterfalls rising from the New York Harbor. Methods to study the impact of an event of this nature are traditionally based on the collection of static information such as surveys and ticket-based people counts, which allow to generate estimates about visitors' presence in specific areas over time. In contrast, our contribution makes use of the dynamic data that visitors generate, such as the amount and distribution of aggregate phone calls and photos taken in different areas of interest and over time. Our analysis provides novel ways to quantify the impact of the public art exhibit on the distribution of visitors and the attractiveness of points of interest in the proximity of the event.

Keywords: digital earth, urban studies, urban indicators, reality mining, digital footprints, pervasive data mining.

1 Introduction

The recent large deployment of mobile devices has led to a massive increase in the volume of data regarding where people have been and when they were there. Access to aggregate measures of people's interactions and communications in the urban environment allow generating digital footprints that could have significant impact on urban and social studies (Microsoft, 2008). Arguably, analysis of these digital footprints can provide novel insights into how people experience the city, revealing different aspects of mobility, travel, and tourism, and allowing to study different attractors in the urban environment. This information can be useful for local authorities, researchers, as well as service providers, such as mobile networks operators. For instance, information about the numbers populating different parts of the city at different times can lead to the development of customized services for citizens, allow accurate timing of service provision that can be based on demand, and more synchronous management of service infrastructure. In addition, in this paper, we analyze these new types of dynamic urban data to estimate the attractiveness and economic impact of points of interests in the city. In order to ensure that the social advantages of these applications are not in conflict with important privacy requirements, researchers and developers in this field must take conscientious, principled, and evident measures to protect people's privacy. In this paper, we consider two types of digital data: (i) highly aggregated, non-personally identifiable records generated by mobile phone usage on the AT&T wireless network; (ii) photos posted publicly on the photo-sharing website Flickr.

We present the methodologies and results of a case study in which we analyze the distribution and density of digital footprints in the area surrounding the New York City Waterfalls to quantify urban attractiveness. The Waterfalls was a public art project of four man-made waterfalls rising from the New York Harbor (in the East River) which were on display from June 26 to October 13, 2008.

Due to the large investments required for the temporary installation, its organizers also wished to study the economic impact of the event. The New York City Economic Development Corporation estimated that nearly 1.4 million people viewed The New York City Waterfalls, whether from an official vantage point, a ferry, or a tour boat (New York City Economic Development Corporation, 2008). Of the 1.4 million Waterfalls viewers, about 79,200 were incremental visitors to the City – people who visited the city or extended their ongoing visit particularly to visit Waterfalls. According to the study, the Waterfalls were viewed by New Yorkers, and by visitors from across the United States as well as from at least 55 other countries. These visitors generated – directly and indirectly – about $69 million of total economic impact on New York City. The Waterfalls were intended to bring visitors and New Yorkers to the waterfront that otherwise may not have done so, raising awareness to New York City's waterfront.

While traditional methods, such as people count and surveys, employed for studying the economic impact generate rather precise estimates of visitors to specific areas, our case study provides novel methods to quantify the influence of the public art exhibition on the distribution of visitors and on the attractiveness of various points on interest in the proximity of the event. Our analysis of cellular network traffic and georeferenced photos provides evidences as to where the more than one million New Yorkers and visitors were attracted in Lower Manhattan and whether the points of interests at the waterfronts increased their attractiveness and popularity during the event.

In more general terms, our contributions are twofold. First, we explore how locals and visitors share the space: our previous work has illustrated the capacity of aggregate digital footprints to uncover the presence and movements of tourists in cities such as Florence and Rome (Girardin et al., 2008). We were able to map their spatial presence, their temporal presence, and their movements within and outside of the city. In addition, the spatial and temporal distribution of tourists of different nationalities seems to be characterized by different types of digital footprints. In this project, we aim to provide additional empirical evidences and more detailed analysis of the mapping of visitors and locals, revealing where they take photos and communicate through their mobile phones. Second, we develop indicators to quantify the evolution of the level of attractiveness of a various points of interest. We argue here that the spatial distribution of visitors and the density of the digital footprints they leave behind reflect the attractiveness of a place. Our indicators are inspired by economics and network theory, and are used to compare the attractiveness of the main points of interests around the Waterfalls by their relative strength, and the evolution of the centrality of the waterfront among the network of points of interest.

In order to explore these questions, our research process follows several steps that start from the collection of digital footprints (Figure 1). One type of digital footprints comes from people's implicit interaction with wireless infrastructures that results, for instance, in location logs produced when carrying a mobile phone that is in constant dialogue with a wireless network. In addition to these automatically generated and implicit data, another type is generated explicitly by a mobile user when generating messages and by Web users when they post content such as photos on public Web sites. Using these data we seek to extract spatio-temporal characteristics such as seasonality, usage patterns, and spatial distribution. In subsequent phases, these parameters inform the formulation of urban indicators that help us quantify the attractiveness of popular areas.

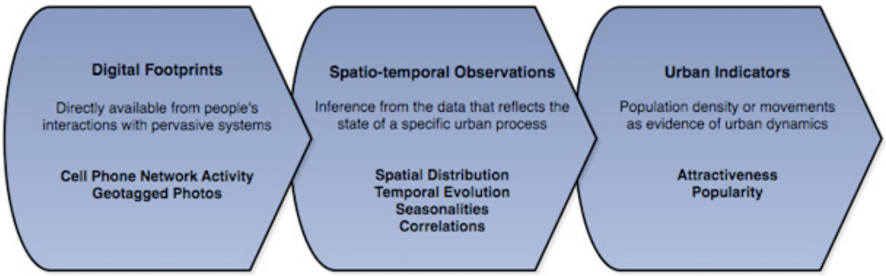

Figure 1. Our study starts with the collection of digital footprints, then the analysis over space and time of their characteristics that feed the definition and application of urban attractiveness indicators.

The following section gives a condensed overview of related research works that exploits digital footprints in the domains of urbanism and tourism. Then, we present the types of data collected, and our methodology used to extract valuable indicators. Finally we conclude with a discussion on the limitations and future works.

2 Related works

People counts, surveys, and other traditional methods to identify the presence of visitors and tourists in a city are often expensive and result in limited empirical data. Methods and models to study the space use with the urban configuration such as Space Syntax (Hillier, 2007) still heavily rely on these kinds of estimates. Similarly, the exploitation of land (e.g. density of hotels) use and census data (e.g. museum revenues) only provides a very static perspective on a city dynamics. The lack of data is especially frustrating for the typical situation where cities are trying to sustain their services with limited human, technical, and financial resources. Today, thanks to the emergence of ubiquitous technologies, new data sources are available. Indeed, the logs produced by users' interaction with wireless and online services could help to create and define new methods of observing, recording, and analyzing aggregate human dynamics in the context of the city (O'Neil et al., 2006), leading to the development of metrics for describing the social and spatial characteristics of the space (Kostakos et al., 2008). This distributed presence of personal devices create, in essence, a vast, geographically aware sensor web (Goodchild, 2007; Zook et al., 2004; Elwood, 2008; Budhathoki et al., 2008) which could use the accumulation of records to reveal collective social behaviors with unprecedented details (Eagle and Pentland, 2006). These digital footprints present an opportunity in urban and tourism studies to build more efficient ways of collecting aggregate information about visitors' activities. For instance, tourists have many ways of leaving electronic trails: prior to their visits they generate server log entries when they consult digital maps (Fisher, 2007) or travel web sites (Wöber, 2007); during their visit, they leave traces on wireless networks (Ahas et al., 2007), whenever they use their mobile phones or through their credit card payments (Houée and Barbier, 2008), and after their visit they may add annotations (Mummidi and Krumm, 2008) and photos (Girardin et al., 2008; Crandall et al., 2009) to digital maps. Examination of such data could complement statistical analysis of collective accommodation, for example, and optimize the provision of customized services. It can also contribute to accurate timing of service provision based on demand (e.g. rescheduling monument opening times based on the presence of tourists), estimation of the economic impact of areas of interests, and, in general, it can facilitate more synchronous management of service infrastructures.

However, there are several key issues when collecting information on urban dynamics. A major concern consists is the privacy and ethical issues related to collecting personal data (Gutman and Stern, 2007). Other issues include the longevity of the studies (e.g. to prevent fatigue effects); the timeliness of the data collection; and the scalability challenge of deploying the data collection, for instance, when dealing with a variety of cellular network standards and providers. Each of the above-mentioned approaches has to face these aspects. Table 1 compares how each performs with respect to these important aspects of tourism and urban studies.

Data capture	**Strength**	**Weakness**	**Example of application**
Land use and census data	Applicable to many scales and over long periods of time	Infrastructure and service static view of urban dynamics	Estimate the tourism intensity of an area
Manual surveys	Capture motivations and reasons in specific areas.	Very costly and applies to a limited time period.	Capture the motivation of a visit and length of the stay.
Near-field communication	Precise real-time mobility data	Costly infrastructure deployment	Describe the social and spatial characteristics of the space (Kostakos et al., 2008)
GPS logs	Precise mobility data	Does not scale well, with survey limited in time and participants	Cluster tourist routes (Asakura and Iryob, 2007)
Cellphone (device-based)	Timely mobility data potentially augmented with in-situ survey.	Does not scale well, with survey limited in time and participants	Context-Aware Experience Sampling to capture the experience in-situ. (Froehlich et al. 2006)
Cellphone (aggregated network-based)	Use existing infrastructure to provide real-time density and mobility data covering multiple scales (neighborhood, city, country)	Reveal phenomena but do not explain the reasons.	Real-time traffic detection (Yim, 2007)
User-generated content	Exploit publically available data with no need of pre-existing infrastructure	Credibility of information and no systematic coverage	Reveal flows of photographers (Girardin et al. 2008)

Table 2. Data capture techniques with their main strength and weakness in the context of tourism and urbanism studies.

In this research work, we consider georeferenced photos made publicly available by individuals on the Web as well as aggregate, non-personally identifiable records generated by mobile phone users who make calls and send text messages using a cellular wireless network. These two data sets are independent of each other.

Previous research has also shown that the widespread usage of mobile phones and the pervasive coverage of cellular networks in urban areas make these technologies efficient tools through which to study both groups (Ratti et al., 2006) and individuals (González et al., 2008), and develop metrics for describing the social and spatial characteristics of the space (Kostakos et al., 2008). For example, analysis of mobile data for vehicle traffic analysis (see Yim, 2007 for a review) can lead generate information about traffic conditions in real-time. In some other efforts cellular network signals were correlated – with limited success – with the actual presence of vehicles and pedestrians in the city (Sevtsuk and Ratti, 2007). In a case study of tourism dynamics in Estonia, Ahas et al. proved that the sampling and analysis of passive mobile positioning data is a promising resource for tourism research and management. They show that this type of aggregated data is highly correlated with accommodation statistics in urban touristic areas. Overall, the advantage of mobile data over traditional tourism statistics is its improved spatial and temporal precision and breadth. While this work highlighted the dynamics of tourism in an entire country (Estonia) for purposes such as obtaining more detailed geographical information about urban versus rural tourism, our study takes place at the scale of a city-neighborhood and leverages the estimated density and movement of visitors to study the attractiveness of the urban space over time.

We particularly focus on the attractiveness of a urban center because they have been the focal point of citizen’s urban life. Therefore, the current limited abilities to monitor of their attractiveness could be regarded as an immediate threat to the liveliness of a city’s economy. As we have seen, the advantage of our approach over traditional tourism and urban statistics is the longevity, scalability and timeliness the analyzed datasets offer.

3 Datasets

We analyzed two types of digital footprints generated by phones or mobile devices that were in physical proximity to the New York City Waterfalls: cellular network activity and photo activity (Table 2). Cellular network activity was measured by summing the aggregated number of calls, the number of text messages, and the overall amount of network traffic generated at each AT&T antenna per hour. Photo activity was measured by summing the number of photographers present in different areas of the city, and the number of photos they took in each location by analyzing photos on the photo sharing website, Flickr (see Girardin et al., 2008 for a more detailed description of the data collection process).

	Cellular Network Activity	**Photo Activity**
Provider	AT&T	Flickr (publicly available)
Coverage	Lower Manhattan and West Brooklyn	New York City
Time period	Aug 2007 to Aug 2008, every hour	Jan 2006 to Aug 2008, every minute

Table 2. Sources and spatio-temporal coverage of the datasets

3.1 Cellular network activity

As part of our research collaboration with the mobile operator, AT&T, we were granted access to anonymous hourly-aggregated records of network activity generated by mobile phone users who made calls on the AT&T network between August 2007 to August 2008. The section of the network under study is serviced by a Base Transceiver Station (BTS) which covers the lower part of Manhattan and the west part of Brooklyn. A BTS represents the elementary unit of the infrastructure that is used to connect users' devices to the mobile phone network wirelessly. It provides connectivity to specific geographic regions called sectors. Each observation constitutes the number of calls that originated and terminated in each of the sectors. Table 3 provides a detailed description of the meaning of each data type. It should be noted that the data can be biased and contain spatial noise. In our case study some of the network connectivity is provided by infrastructure on the other side of the East River, thus affecting the ability to capture fine-grained information about the location of mobile phone users. Moreover, when an ongoing call is handed over to another antenna, the location of the call activity is still associated to the place where the call started, which creates additional noise. Finally, several additional factors directly affect the capacity to estimate network activity in specific areas. For instance, the dimension of a wireless sector can vary greatly, depending on the built environment it services and the phone used. Also, some sectors can partially overlap and provide signal to similar areas, thus making it difficult to determine the location of calls made through these sectors.

Data type	**Description**
Aggregated calls	Number and duration of calls originated and terminated in an area
Aggregated Call Detail Records (CDR)	A CDR is the record produced by a telephone exchange. These aggregated records provide information about each call or text, such as time (measured by the hour), user's home location, and the BTS it is connected to. The home location of a user is determined a the area code of a mobile telephone number for U.S.-registered phones and the country code associated with the mobile telephone number of foreign-registered phones.

Table 3. Descriptions of the types of aggregated cellular network traffic data

Our collaborators granted us limited access to CDR data. It is important to note that many U.S. mobile phone customers may own telephone numbers with area codes that do not reflect the state at which they actually reside. Also, foreign visitors may acquire U.S. SIM cards and mobile telephone numbers for the duration of their stay in the U.S. Thus, there can be some inaccuracies in our inferences about the home locations of mobile phone users.

3.2 Georeferenced photos on Flickr

It's common for visitors and tourists is to take photos during their trips and use a web photo sharing platform such as Flickr to share and organize photos with geographical attributes. Each time a photo is anchored to a physical location, Flickr assigns longitude and latitude values together with an accuracy attribute derived from the zoom level on a map that is made available for users to position their photos. Photos positioned when the user zooms in at the street level receive a higher accuracy estimate than ones positioned when the user had pulled back in the online map view. The system also adds metadata embedded by the camera in the image through the Exchangeable Image File Format (EXIF) information, completing the spatiotemporal information (Table 4).

Data type	Description	Size
Photographers	60% of the cases - nationality is disclosed. Activity is profiled to infer whether users are New York residents or visitors	29.235 photographers
Photos	Geographical coordinates disclosed by the photographers; date and time extracted from the digital camera metadata; semantic description of the photo is provided by the photographer.	1.197.287 photos

Table 4. Description of the Flickr dataset

We pre-processed the data by classifying local photographers and visiting photographers based on the their presence in the area over time as the discriminating factor with the aim of capturing the one-time tourists. We divided the time period into 30-day intervals and calculated the number of periods for which each photographer was active in an area. If a photographer took all his/her photos within one period of 30 days, we classified him/her as a visitor, while if there was an interval greater than 30 days between two photos taken, we classified him/her as resident.

We used the Flickr API to retrieve the coordinates of photos and their accuracy, the time at which they were taken, and we also obfuscated the identifiers of their owners. The mapping of these data allowed us to detect the main areas of photographic activities in New York because the accumulation of georeferenced photos over a period of time reveals the boundaries of areas of interest in a neighborhood. In addition, the processing of a chronologically ordered set of photos revealed the traces of the photographers, that is their spatiotemporal movements in the urban space.

4 Method

Our method aims at quantifying the distribution of digital footprints over the area of study as precisely as possible. This is more difficult in the case of cellular activity than in the case of photo activity because the former is measured only in discrete locations (i.e. at the level of the BTS) while the latter is continuous over the space. For the cellular activity, we computed a radio map of partitions generated by the overlapping of BTS sectors: activity inside each partition was considered uniform and was computed by taking into account the activity of each overlapping sector (see details below). For the photo activity, we employed a similar process that stores photos in equal size partitions, forming a matrix. The resulting data structures allow us to map the density and flows of footprints over space and time: on top of them, we defined probes as spaces to analyze and compare the dynamics of particular areas of interest. The remainder of this section describes this method in more detail.

4.1 Radio map

Our first step was to estimate the density of the traffic over space according to the topology of the wireless network. This is done by preprocessing wireless propagation data and generating a radio map that aims at overcoming the inherent problems of resolution and reliability of the cellular network statistics at relatively small urban areas.

Each area of wireless coverage is divided into sectors. Each area is controlled by a transceiver that is mounted on a BTS and connects a mobile device to the rest of the network. The boundaries of each sector, which are necessary in order to compute the distribution of cellular activity, are not well defined and depend on the location of the BTS station itself. A standard approach is to compute the Voronoi diagram based on the location of the BTS stations, thus assuming that the best serving station is the closest one to any point in space. However, this approach is imprecise, because many elements of the urban landscape can interfere with the coverage of the BTS. This method also does not work well with rather the small-sized areas of interested selected for our research. Therefore, we employed a propagation model based on the Okumura-Hata model (Seybold, 2005) to estimate the boundaries of each sector based on the location, height, azimuth, Effective Isotropic Radiated

Power (EIRP), type of antenna, and frequency served of each BTS, together with an analysis of the physical environment in the area which the BTS services (e.g. presence of a river). The model produces estimates of the coverage of each sector, whose overlap was used to generate a radio map of the study area formed by around 9900 nonoverlapping partitions. We estimated the activity at each partition by summing the weighted contributions of all the overlapping sectors: as a result, each partition reports on estimate of the network activity generated in its coverage area.

4.2 Areas of interest

To explore the impact of the event at a neighborhood scale and the evolution of the attractiveness of the surrounding areas, we defined the major attractions in the proximity of the Waterfalls such as the World Trade Center site, Wall Street, City Hall, and the Brooklyn Bridge (Figure 2).

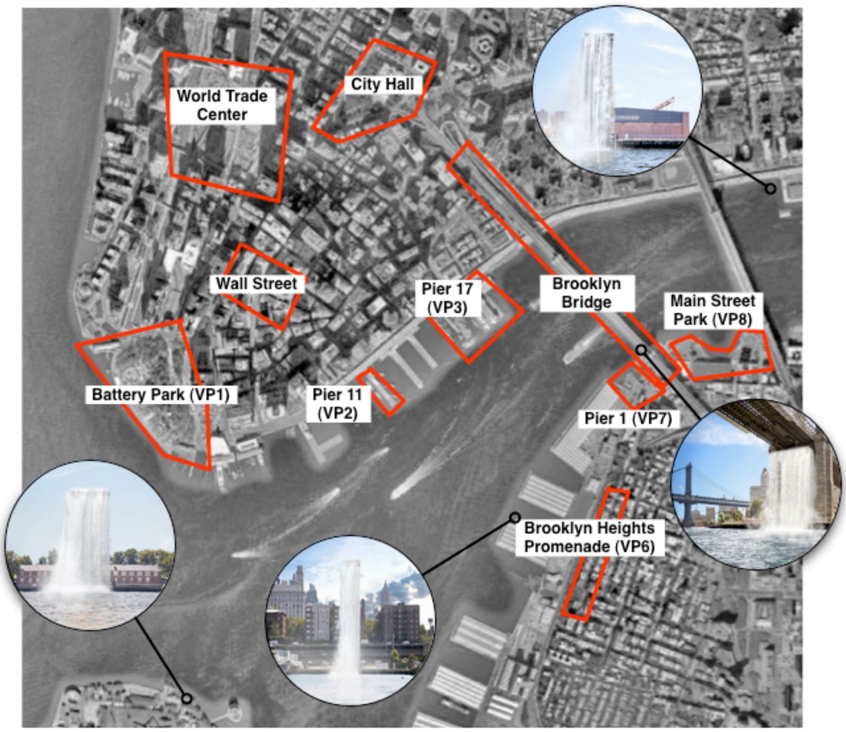

Figure 2. Location of the four Waterfalls and definition in red, the main vantage points (VP) and attractions in proximity to the New York Waterfalls exhibit

The probes vary widely in dimension: they could be as large as the financial district or as small as Pier 1, a pier renovated to serve as vantage point for the exhibit. The activity for each area of interest differs from the dataset. For the Flickr dataset, we simply sum the number of georeferenced photos taken and photographers active within each of the probe. For the cellphone data, the activity for each area of interest was estimated by considering the relative weights of each sector's contribution to each element of the partition, and the relative weights of each partition's contribution to each area of interest. Following, we detail this process.

4.3 Interpolation model of network activity at each area of interest

Our approach is based on the following assumptions:

1. Phone usage is not uniformly distributed over the coverage of each sector.
2. Contributions of each BTS to each partition is inversely proportional to the overall number of transceiver that service to the partition.

In the example on Figure 3, if a transceiver T1 coverage is divided into two partitions P1 and P2, where P1 is covered only by T1, and P2 is covered by T1 and another transceiver T2, then the density of activity contributed by T1 to P1 should be double the density of activity contributed to P2, and the same holds for T2 with respect to P2 and P3.

Furthermore, P4 is serviced by T3 only, P5 by T3 T4 and T5, P6 by T3 and T5, P7 by T4 and T5, and P8 by T5 only. Therefore:

For T3: d(P4) = 2 x d(P6) = 3 x d(P5), and s(P4) + s(P5) + s(P6) = s(T3);

For T4: 2 x d(P7) = 3 x d(P5), and s(P7) + s(P5) = s(T4);

For T5: d(P8) = 2 x d(P6), and s(P8) + s(P6) = s(T5);

Where d is the density of activity contributed

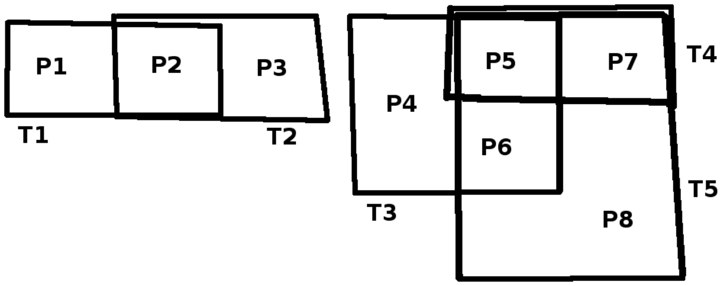

Figure 3. Interpolation model of network activity at each area of interest

The method described in this section allows us to estimate the activity for each area of interest without imposing strong a priori assumptions about the distribution of the activity. The results obtained can be used to perform analysis on the data and uncover their spatio-temporal characteristics: this process and its results are described in the following section.

5 Observations of presence and activity

This section describes the spatio-temporal characteristics of the data. Particularly, it focuses on the spatial distribution of presence of locals and visitors and on the evolution and seasonal patterns of their activity over time. These observations allow us to identify the major activities in space and time that lead to the production of digital footprints.

5.1 Spatial distribution of locals and visitors

For the week of August 10 to August 17, 2008, AT&T provided us with hourly aggregated data about cellular network traffic indicating the number of non-personally identifiable phone calls for each registration location of mobile phones. The registration location of locals and visitors is determined based on the area code of the handset's mobile telephone number for U.S. phones and the country code for foreign phones. This allowed us to count the activity from mobile phones registered in New York, and to quantify how much activity was associated with a mobile phone registered in the United States but outside New York, and how much activity involved a mobile phone registered outside the United States.

While it may not be always true, we considered it reasonable to assume that locals generate the majority of calls from mobile phone registered in New York, and that visitors generate the majority of calls that involve mobile phones registered outside New York. With this assumption, we were able to map the presence of non-identifiable locals and visitors on an average weekday and on weekend (Figure 4). The observation revealed that visitors enjoy Lower Manhattan and its main areas of interest, particularly during the weekend, much more than they visit Brooklyn, with the remarkable exceptions of Pier 1 and the waterfront. On the other hand, locals show a well-spread activity in space with stronger presence in Brooklyn over the weekend.

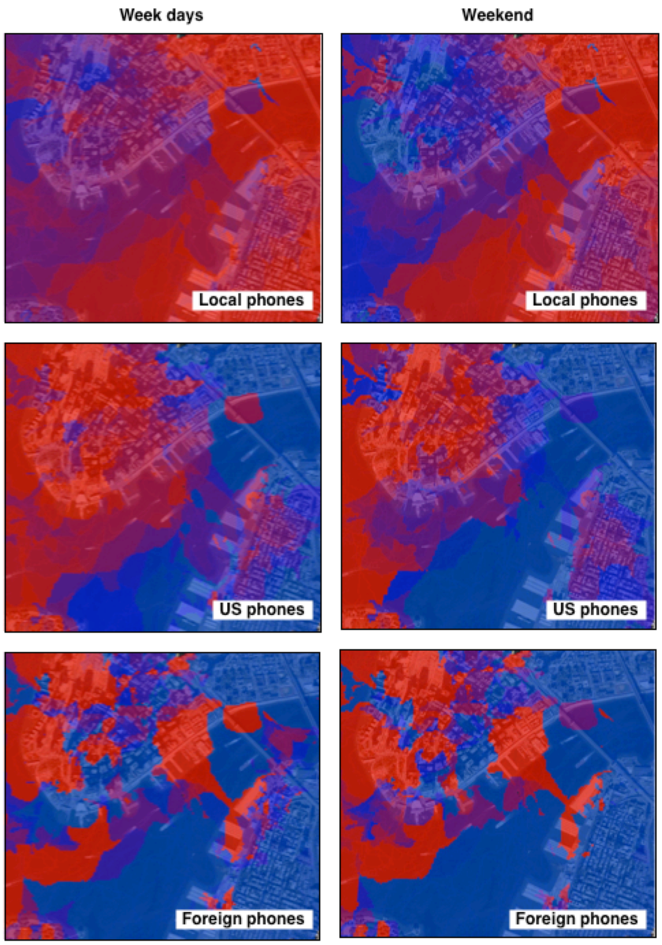

Figure 4. Spatial distribution of locals (New Yorkers), US visitors, and foreign visitors in the proximity of the Waterfalls. High density areas of cellular network activity are in red. Locals withdraw from Lower Manhattan on the weekends and the use foreign phones is limited to certain areas of the neighborhood.

Mapping of the density of photographers brought another perspective on the distribution of visitors. It allowed us to observe the evolution of their activity over three consecutive years (Figure 5), revealing the main areas of interest for photographers, in particular the Brooklyn Bridge, the World Trade Center site, and Battery Park.

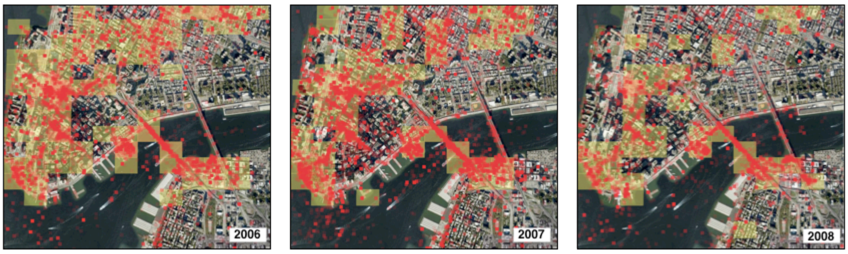

Figure 5. Spatial distribution of photographers (in yellow) and photos (in red) in Summer 2006, 2007, and 2008 in Lower Manhattan and West Brooklyn.

5.2 Evolution of the activity

While the previous observation allowed us to study the spatial distribution of locals and visitors, it didn't provide insights as to the evolution of their activity over time. To identify the major trends of activity, we plotted stacked bar charts that display the daily patterns of activity for each probe between August 2007 and August 2008. We generated two versions of the charts: one which represents the absolute values of phone calls – useful to understand both the behavior of each area of interest and the overall trend, and another which represents the relative activity of each area of interest with respect to the others – useful to compare variations in behavior between probes.

Here again, we selected phone calls as a proxy for presence of people. Figure 6 shows the evolution of the daily density of phone call activity between August 2007 to August 2008, i.e. the average number of phone calls originated or terminated in each area of interest in one day, per unit of surface. The observation shows that there is a year-long trend of positive growth in the overall number of phone calls and that most of the growth originated in an increased activity in Brooklyn (VP6 and VP8), with almost doubles in activity during that period. Moreover, it shows the presence of strong weekly seasonality, which causes the phone call activity to drop over the weekends to about half the activity of workdays with slight variations among the different areas of interest.

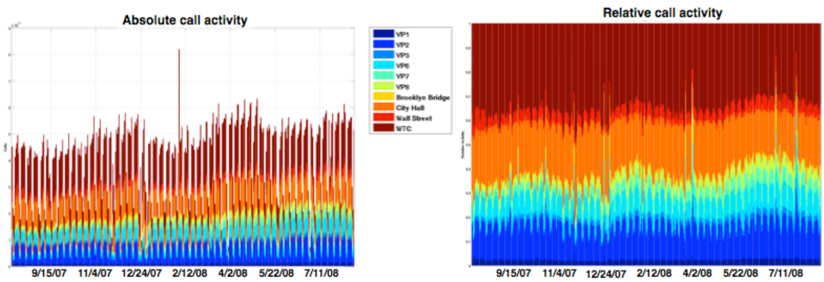

Figure 6. Daily absolute (left) and relative (right) density of phone calls per POI. Note: values on the vertical axes have been multiplied by a constant factor.

Seasonality is confirmed by when observing the absolute density, which also reveals that while some areas of interest tend to have less activity over the weekends, others exhibit an increase, a divergence that can help us understand the type of traffic generated at each area of interest (e.g. work-related versus leisure-related).

5.3 Temporal patterns

Motivated by the results of our previous observations, we decided to explore temporal seasonalities further on different time horizons and with the use of spider charts. Figure 7 on the left shows the average phone call activity throughout the day (in slots of three hours each, from midnight to 3 am, from 3 am to 6 am, and so forth): all the areas of interest present the same behavior at night and during the afternoon, while they exhibit different behaviors during the evening. Figure 7 in the middle reveals the average phone call activity per day throughout the week. It shows similar behavior during workdays across probes, and variation during weekends, when some areas of interest drop to an activity level that is about 30% of that during workdays. Others area of interest maintain an activity of about 60% during weekends. Finally, Figure 7 on the right shows the average activity level per month throughout the year, presenting an overall higher variability of behaviors, yet still showing clearly different activity levels between August to November.

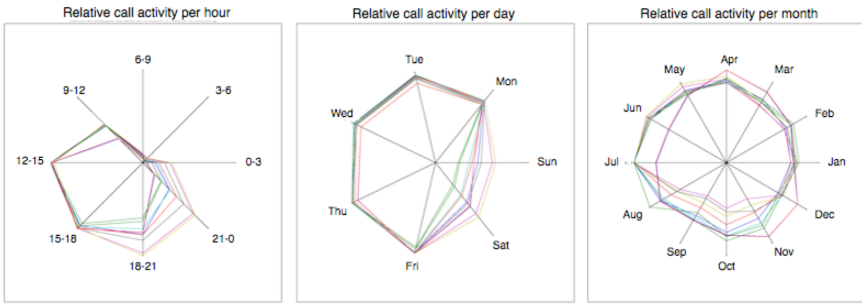

Figure 7: Temporal patterns of phone activity between POIs, per slots of three hours throughout the day (on the left), per day throughout the week (enter), per month throughout the year (on the right) - period August 2007 to August 2008.

The observations presented in this section showed that Lower Manhattan attracts more visitors than West Brooklyn, which exhibits the typical characteristics of a residential area with fewer features of tourist activity. The observations also show that there are clear seasonal differences between areas of interest, in particular at different hours of the day and during different days of the week. These results raise new questions: which areas of interest attract more tourists during the weekend? How can we quantify the growth in attractiveness at different areas over time, and which areas grew more in activity from one summer to another? In order to answer these questions, we defined indicators of urban attractiveness based on the relative density of digital footprints. We ran a comparison between the areas of interest around the Waterfalls as well as with respect to the overall New York City metropolitan area. These indicators are described in the following section.

6 Urban indicators of attractiveness and popularity

In Arabic the word for indicator means pointer, which describes how an indicator is intended to point towards some desirable state or course of action. Urban indicators are about the interface between city management and data. An indicator will often be benchmark against which policymakers and the public can assess change. Indeed, indicators are not data, rather they are models simplifying a complex subject to a few numbers which can be easily grasped and understood (de Villa and Westfall, 2001). There is a wide range of urban indicator applications from macro (i.e. global and national) to micro levels (neighborhoods) developed by international indicator initiatives or cities authorities themselves. To our knowledge, the notion of attractiveness indicators has only been applied at a macro scale to compare the quality of life among major cities.

In contrast, our observations of the cellular network aggregate traffic and photographers activity described the density and movements of locals and visitors over a very defined space and time. This analysis was performed particularly with respect to the main areas of interest on the waterfront in Lower Manhattan and Brooklyn, where people could find vantage points to observe the waterfalls. In this section, we explore the use of indicators to measure these observations and quantify the evolution of attractiveness and the popularity of areas of interest in proximity to the Waterfalls public exhibit.

6.1 Attractiveness

We hypothesized that the density of the digital footprints that visitors leave behind gives an indication of the attractiveness of places; that is that these places of have beneficial features for work, social interaction, or sightseeing purposes. In addition, we conceptualize urban attractiveness as a property of a well-defined place can have variable size. Therefore, we developed several indicators to compare the evolution of the attractiveness of different areas around the waterfront and of areas of interest in proximity of the exhibit, based on their Comparative Relative Strength (CRS).

The CRS indicator compares the activity of one area of interest with respect to the overall activity of the city. The values are normalized over time and space therefore not relying on the absolute number of photographers but comparing their relative activity. When the CRS indicator grows in time, it shows that the area of interest is performing better than the overall city because it is attracting more or losing less activity than the rest of the city. We used three different proxies to measure the attractiveness of areas of interest: the presence of photographers, the number of calls, and the ratio of calls made by locals versus visitors.

6.1.1 Attractiveness based on the presence of photographers

The table below (Table 5) shows the variations of the CRS indicator based on the presence of photographers during the summers (June to October) of 2006, 2007, and 2008. It reveals a positive growth in the waterfront's attractiveness of 8.2% in summer 2007 and 20.7% in summer 2008 with respect to that of other areas of interest in New York City, such as Time Square and Central Park. It should be noted that the maximum growth in attractiveness (+29.9%), observed during summer 2008 was recorded in DUMBO in Brooklyn. This was probably supported by the increased presence of photographers at the proximate vantage points of Pier 1 and Main Street Park, elicited by the Waterfalls.

	Photographers 2006	**Photographers 2007**	**Photographers 2008**	**CRS 2006**	**CRS 2007**	**CRS 2008**	**2006 to 2007**	**2007 to 2008**
Central Park	1874	2619	1537	0.111	0.101	0.100	-0.091	-0.008
Chelsea	1146	1790	1125	0.068	0.069	0.073	0.015	0.062
East Village	652	971	606	0.038	0.037	0.039	-0.031	0.054
WTC site	564	775	374	0.032	0.029	0.024	-0.075	-0.184
Time Square	1227	1883	1026	0.073	0.072	0.067	-0.002	-0.079
Vantage Points	538	896	640	0.032	0.034	0.041	0.082	0.207

Table 5. Variation of the CRS indicators from 2006 to 2008

6.1.2 Attractiveness based on the number of calls

The graph below (Figure 8) shows the trend of CRS of number of phone calls initiated or received every hour between August 2007 to August 2008, at each area of interest. We blurred the absolute values with a random factor to keep these data confidential. The CRS of number of phone calls reveals an increase in vantage points' attractiveness of 39.1% with respect to the attractiveness of other areas of interests in the vicinity, like the World Trade Center site, City Hall, and Wall Street. Interestingly, Pier 1 doubles its attractiveness (105%) over this period. Other areas of interest in the vicinity also experience increased attractiveness (Main Street Park, Brooklyn Bridge, and South Street Market).

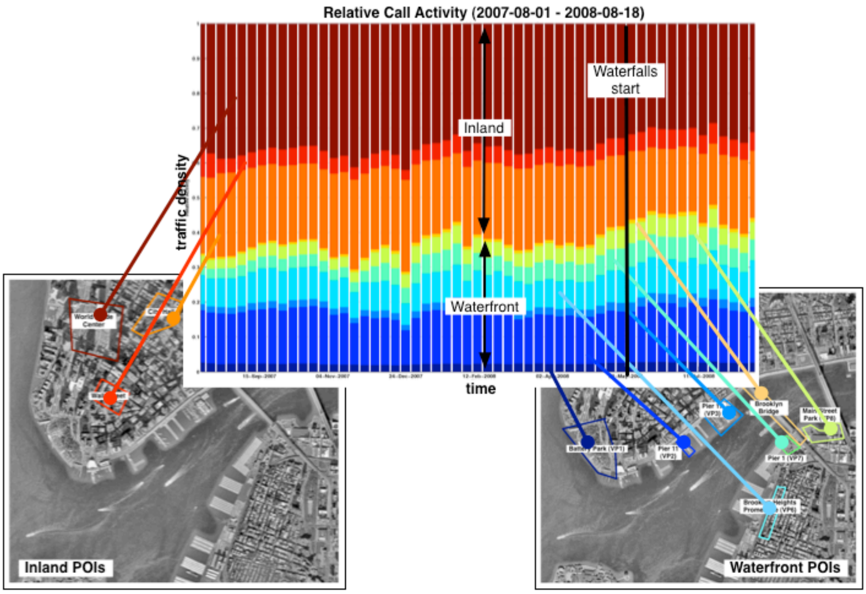

Figure 8. Evolution of Comparative Relative Strength of relative phone call activity among the exhibit vantage points and other city attractions in proximity (WTC site, Wall Street, City Hall) between August 2007 to August 2008

6.1.3 Comparison of attractiveness for locals and visitors

The figure below (Figure 9) shows the CRS of three types of calls (originated from mobile phones registered in New York, the US and the rest of the World) during workdays and weekends for each area of interest. The first set of histograms shows the percentage variation of the number of calls (almost always negative because weekends are characterized by a general reduction in call activity), while the second set shows the percentage variation in CRS.

The percentage of foreign visitors' calls shows an average growth of 88% across vantage points when comparing weekdays and weekends, while the average growth of other areas of interest is 77%. However, the average CRS of US visitors' calls over the vantage points shows growth of only 15%, while the growth at the areas of interest is 31% on average. This means that while the vantage points tend to outperform the other areas of interest in attracting activity of foreign visitors, they perform worse in attracting activity of US visitors.

It should be noted that the WTC site is clearly a major area of interest for tourists in Lower Manhattan, with a locals' calling activity decreasing to less than 50% during weekends when compared to weekdays. Other areas such as City Hall and Battery Park show a similar distribution of calling activity, with New Yorkers leaving the place to visitors from the US and abroad during weekends.

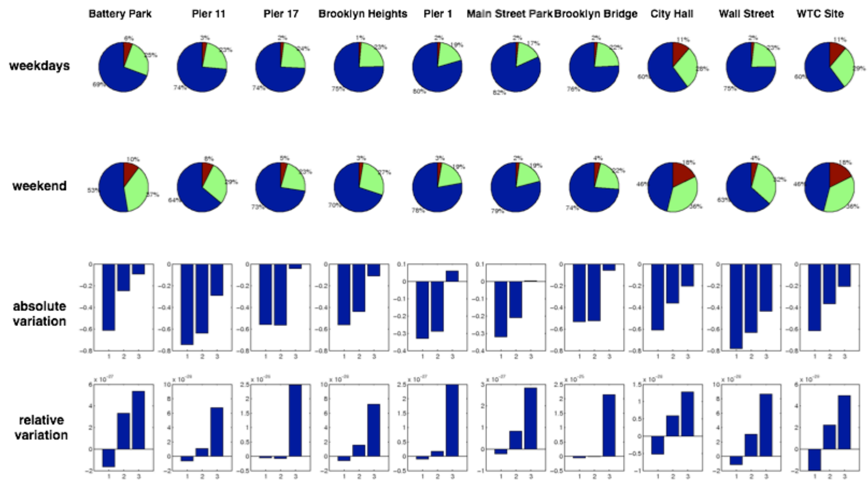

Figure 9. CRS and percentage variations for locals' (blue,1), US visitors' (green,2) and foreign visitors' calls (red,3) at the vantage points and main points of interests between weekdays and the weekend.

6.2 Popularity

We assessed the popularity of an area of interest by studying its ties with other areas in the city. The stronger the ties, the more frequently an area is accessible from other places, as it becomes part of a popular route. This was measured by applying network analysis techniques to study the connectivity of a network in which the nodes represent areas of interest and the arches represent flows of people between them. Flows were estimated by analyzing consecutive time stamps tagged to Flickr photos in conjunction with the reported location at which a photo was taken.

6.2.1 Popularity based on centrality

The centrality of an area of interest determines its level of integration to the popular flows of photographers. The PlaceRank indicator, inspired by the PageRank indicator developed by Google

to order the importance of Web pages (see Brin and Page, 1998 for a detailed description of the PageRank calculation), determines the centrality of a location within a set of areas of interest based on the amount of digital footprints generated in each area and the traces that connect them. In particular, if more visitors visit place A than place B, then we can say that the former is more popular than the latter in the network of tourist destinations. Moreover, if the same amount of people move from pace A to a new place C and from place B to a new place D, we can also say that place C is more popular than place D because place A is more popular than place B.
We computed the PlaceRank values for the areas of interest, using aggregate values during 2006, 2007, and 2008. Figure 10 helps in interpreting the data by showing a graphical representation of the connectivity of areas of interest based on the number of photographers moving within each location.

The PlaceRank indicator reveals that between 2006 and 2007 the vantage points lost their centrality by 15% while the other areas of interest increased their centrality by 10%. However, between 2007 and 2008, the vantage points gained 56% while the other areas of interest lost 30%. In 2008, the vantage points appear as central as the other areas of interest, meaning that they are on the tourist path as much as the other areas of interest in that section of the city.

Figure 10. Evolution of the flows of photographers in proximity to the exhibit based on the analysis of photos generated between June - October, 2006, June - October, 2007, and June - August 15 in 2008. At that year of the Waterfalls, VP3, VP6 and VP7 massively increase their PlaceRank.

7 Discussion

The increasing deployment of wireless and mobile devices makes new types of dynamic data available. Through passive and active interactions with these ubiquitous technologies, people generate digital footprints which can be used to describe and analyze urban environments as well as human activity on a detailed level and at large scale.

In this case study, we collected and analyze annonimized and aggregated cellular network traffic data and georeferenced photos that were made publically available on line to reveal several types of digital footprints. We illustrate the use these footprints to develop observations and define indicators that can inform urban design, planning, and management processes. Our analysis allowed us to track the evolution in attractiveness of different areas in the Lower Manhattan and Brooklyn waterfronts over time. The new information was used to supplement a study which used traditional means to quantify the impact of the New York Waterfalls public event (e.g. manual counts and surveys) that was shown at the New York waterfront between June to October 2008. Our approach relied on several indicators of urban attractiveness which we developed in inspiration by financial indicators and network theory. For instance, we compared the attractiveness of major points of interests in New York based on the relative density of digital footprints. We also analyzed the flows of visitors between several points of interest in Lower Manhattan to track the evolution of centrality of the waterfront area in comparison to the other points of interest. Mapping this new type of digital footprint analysis shows the capacity of an event to drive people to less explored parts of a city over time, information which can be highly valuable for urban design and tourism studies.

Furthermore, in the traditional urban design process, practitioners often have limited capacity to evaluate their design due to difficulties in performing reliable post-occupancy studies, which are rarely performed for that reason (Kozlowski, 2007). This case study shows that the emergence of digital footprints creates an opportunity to evaluate in detail the use of space, the impact of events, and the evolution of the built environment. This approach could not only better inform urban design decisions and city management, but also enable local authorities to provide timely evidences to the public about the use of space and about the impact of interventions with the urban fabric. Indeed, the integration of our results in the official study of the economic impact of the New York

Waterfalls public art project shows that the indicators proposed in this paper offer useful measures to complement traditional methods.

Our approach produced several novel research contributions for the utilization of digital footprints. The research effort to quantify urban attractiveness using the distribution and density of digital footprints led us to explore the mapping of the spatial distribution of visitors, and to develop indicators to compare the evolution in attractiveness of the waterfront with respect to other areas in the city.

At this stage in our research, even though the measurements and visualizations performed concur with the traditional impact study of the Waterfalls, the extent of their reliability is still unclear as it is the case for approaches based on user-generated content (Flanagan and Metzger, 2008). Indeed, in some cases our case study detects weak signals generated by a diffuse population over a long period of time in one of the noisiest cities in the world in terms of wireless network usage. For instance, the location of Vantage Point 7 at Pier 1 suggests that the temporal measurements of visitors should be impaired by the noise of nearby heavy traffic on the Manhattan Bridge. Therefore, if the area of study is much smaller than the size of the area of interest, it limits the reliability of the results. Also, due to the unobstructed path available above the surface of the East River, a BTS at the waterfront can capture traffic across river, creating a bias that is hard to measure.

Following the results of this case study, we identified three main areas for future work: an improvement in the quality of observations; further development of additional indicators, as well as visual analytics to explore and communicate the study of digital footprints.

Improving the radio coverage maps to reliably distribute data non-uniformly over each sector will reduce limitations in the quality and resolution of the measured data and increase their fidelity to the physical and social worlds. One possible solution could be to perform on-site measurements and mapping of BTS signal to refine the estimation of its coverage. Second, there is a need to estimate the reliability of the results of analyses of digital footprints. The precision of the results depends, among other factors, on the density of BTSs in proximity to the area of interest, and on the consequent ratio between the coverage area of each BTS and the area of study.

Third the dynamic nature of digital footprints and their fluctuations in space and time pose new challenges. It is necessary to calibrate the data using information collected in more traditional means, such as surveys and census data. These shortcomings currently limit the usability of digital footprint information for city management and decision-making. However, its visualization is already offering great tools to communicate different features of activity in urban areas. Along with interactive software, visualization is a useful tool for a multitude of actors in the city such as researchers, interests groups, practitioners, and municipal governments, to discuss how to interpret data and put information in context.

Our analysis could be used not only to describe the attractiveness of a place, but also to further differentiate between places of different types based on the first explorations by Reades et al, (2007). For example, an area with strong calling activity and weak photographic activity could be primarily commercial; one with weak calling activity and weak photographic activity could be rendered residential; one with strong calling activity and strong photographic activity could be friendly towards tourist and leisure-related activities. Similarly, an outdoor area which has strong attractiveness indicators during adverse weather conditions could suggest that it is critical for visitors; an indoor area with weak attractiveness indicators during averse weather conditions could indicate that it may not be easily accessible.

References

Ahas, R., Aasa, A., Silm, S., and Tiru, M. (2007). Mobile positioning data in tourism studies and monitoring: Case study in tartu, estonia. *In Marianna Sigala, L. M. and Murphy, J., editors, Information and Communication Technologies in Tourism 2007*, Ljubljana, Slovenia. Springer Vienna.

Asakura, Y. and Iryob, T. (2007). Analysis of tourist behaviour based on the tracking data collected using a mobile communication instrument. *Transportation Research Part A: Policy and Practice*, 41(7):684–690.

Budhathoki, N., Bruce, B., and Nedovic-Budic, Z. (2008). Reconceptualizing the role of the user of spatial data infrastructure. *GeoJournal*, 72(3):149–160.

Brin, S. and Page, L. (1998). The anatomy of a large-scale hypertextual web search engine. *Computer Networks and ISDN Systems*, 30(1-7):107–117.

Crandall, D. J., Backstrom, L., Huttenlocher, D., and Kleinberg, J. (2009). Mapping the world's photos. In WWW '09: *Proceedings of the 18th international conference on World wide web*, pages 761–770, New York, NY, USA. ACM.

de Villa, V. and Westfall, M. S., editors (2001). *Urban Indicators for Managing Cities: Cities Data Book*. ADB.

Eagle, N. and Pentland, A. S. (2006). Reality mining: sensing complex social systems. *Personal Ubiquitous Computing*, 10(4):255–268.

Elwood, S. (2008). Volunteered geographic information: key questions, concepts and methods to guide emerging research and practice. *GeoJournal*, 72(3):133–135.

Fisher, D. (2007). Hotmap: Looking at geographic attention. *IEEE Trans. Vis. Comput. Graph.*, 13(6):1184–1191.

Flanagin, A. and Metzger, M. (2008). The credibility of volunteered geographic information. *GeoJournal*, 72(3):137–148.

Froehlich, J., Chen, M. Y., Smith, I. E., and Potter, F. (2006). Voting with your feet: An investigative study of the relationship between place visit behavior and preference. In Dourish, P. and Friday, A., editors, Ubicomp, *Lecture Notes in Computer Science*, pages 333–350. Springer Berlin / Heidelberg.

Girardin, F., Calabrese, F., Dal Fiore, F., Ratti, C., and Blat, J. (2008). Digital footprinting: Uncovering tourists with user-generated content. *IEEE Pervasive Computing*, 7(4):36–43.

González, M. C., Hidalgo, C. A., and Barabási, A.-L. (2008). Understanding individual human mobility patterns. *Nature*, (453):779–782.

Goodchild, M. F. (2007). Citizens as voluntary sensors: Spatial data infrastructure in the world of web 2.0. *International Journal of Spatial Data Infrastructures Research*, 2:24–32.

Gutman, M. and Stern, P., editors (2007). *Putting People on the Map: Protecting Confidentiality with Linked Social-Spatial Data*. National Academies Press.

Hillier, B. (2007). Space is the Machine: A Configurational Theory of Architecture. Space Syntax, London, UK.

Houée, M. and Barbier, C. (2008). Estimating foreign visitors flows from motorways toll management system. In *9th International Forum on Tourism Statistics*.

Kostakos, V., Nicolai, T., Yoneki, E., O'neill, E., Kenn, H., and Crowcroft, J. (2008). Understanding and measuring the urban pervasive infrastructure. *Personal and Ubiquitous Computing*.

Kozlowski, M. (2007). *Urban Design: Shaping Attractiveness of the Urban Environment with the End-Users*. PhD thesis, University of Queensland, School of Geography, Planning and Architecture.

Microsoft (2008). *Being human: Human-computer interaction in the year 2020*. Technical report, Microsoft Research Ltd, Cambridge. http://research.microsoft.com/en-us/um/cambridge/projects/hci2020/downloads/BeingHuman_A4.pdf

Mummidi, L. N. and Krumm, J. (2008). Discovering points of interest from users' map annotations. *GeoJournal*, pages 215–227.

New York City Economic Development Corporation. (2008). *The new york city waterfalls: The economic impact of a public art work*. http://www.nyc.gov/html/om/pdf/2008/waterfalls_economic_impact_report.pdf. [accessed 25 January 2009].

O'Neill, E., Kostakos, V., Kindberg, T., gen. Schieck, A. F., Penn, A., Fraser, D. S., and Jones, T. (2006). Instrumenting the city: Developing methods for observing and understanding the digital cityscape. In *Ubicomp*, pages 315–332.

Ratti, C., Pulselli, R. M., Williams, S., and Frenchman, D. (2006). Mobile landscapes: Using location data from cell-phones for urban analysis. *Environment and Planning B: Planning and Design*, 33(5):727 – 748.

Reades, J., Calabrese, F., Sevtsuk, A., and Ratti, C. (2007). Cellular census: Explorations in urban data collection. *IEEE Pervasive Computing*, 6(3):30–38.

Sevtsuk, A. and Ratti, C. (2007). Mobile surveys. In *Urbanism of Track 2007*. Delft University Press.

Seybold, J. S. (2005). *Introduction to RF Propagation*. Wiley-IEEE

Wöber, K. (2007). Similarities in information search of city break travelers — a web usage mining exercise. In *Information and Communication Technologies in Tourism 2007*, pages 77–86.

Yim, Y. (2003). *The state of cellular probes*. Technical report, California Partners for Advanced Transit and Highways (PATH).

Zook, M., Dodge, M., Aoyama, Y., and Townsend, A. (2004). New digital geographies: Information, communication, and place. *Geography and Technology*, pages 155–176.

7. Discussion and perspectives

This final chapter both summarizes the results and contributions of this thesis, and discusses their relevance, context, and limitations. Each open issue and challenge calls for further research that we describe.

7.1. People as sensors; people as actors

The ubiquitous technologies that afford us new flexibility in conducting our daily activities are simultaneously providing the means to study our activities in time and space. In February 2009, Flickr broke the Hundred Million georeferenced photos count (over a total of 3 billion photos in the repository). This represents an unprecedented amount of publicly accessible data produced through people's interactions involving the web and mobile devices. In this thesis we have explored how the logs, fruits of these interactions, could reveal elements of human and social use of the ubiquitous technology itself (Chapter 2, location-awareness and collaboration), and people's mobility and travel behaviors (Chapter 4, air passengers experiences; Chapter 5, tourist dynamics). These latter evidences could be employed as indicators of the evolution of the attractiveness of the urban environment (Chapter 6) amongst other things.

We also focused on the human side of these data. Besides acting as sensors of individuals and groups' presence and mobility, they are often produced intentionally. For instance, users uploading of georeferenced photos can be seen as an act of communication with a goal to share or index a specific moment in space and time. This "I was here" brings a notion of subjectivity to the relation of people with space and place (Dourish, 2006). The effort of an individual to take a photo, select it, upload it onto a web-sharing platform and georeference it can be more powerful than any survey or GPS log that researchers interested in human space-time activity could access in the past. Therefore, automating this process could harm the richness of this explicit interaction with geoinformation. We have observed this underwhelming effect of automation of location disclosure in our pervasive game, CatchBob! (Chapter 2). People are actors, generating voluntarily (or not) digital footprints and they use ubiquitous geographic information to take decisions. Another human side worth stressing is that the integration of location-aware systems alters the relations of humans with others and with the environment. We have described evidences of strategies based on the knowledge of the space and the shortcomings of the system to take decisions (Chapter 3, taxi drivers). For instance, one of the taxi drivers described how he would follow his instinct and start to "improvise" and depending on the circumstances, when a conflict emerges between his navigation system and his intuition, revealing how location and opportunities determine the action as theorized by Suchman (1987). In our context, the understanding of the limitations and the imperfection of the technology seems part of the knowledge. Similar strategies emerged to handle the spatial uncertainty present in our pervasive game (Chapter 2, CatchBob!). People adapt to the technology, but also adapt the technology to them, for instance by integrating it into an ecosystem of artifacts to support their navigation and knowledge of a city (Chapter 3, taxi drivers). These early adopters of ubiquitous technologies act within a co-evolution process with their navigation system.

7.2. Discussed summary of the contributions

This thesis contributes to a thorough understanding of different aspects of the explicit and implicit human interactions with ubiquitous geoinformation, particularly the effect of the fluctuating geoinformation quality on the interaction with location-aware systems; and the effect of the human interactions with location-aware system on the ability to detect movement and presence in space and time. At this stage we could rephrase with more detail the introduction, which summarizes the main contributions of this thesis. But this detail is already present in the contributions of each paper in the previous chapters, and thus it seems more appropriate to stress and discuss some aspects taking an "overall scale" point of view.

Our methodological approach used qualitative, quantitative and design science research to produce guidelines as well as more factual knowledge. It is based on an interplay of techniques and results linking the case studies (Figure 3). Let us stress that the varied approaches applied to varied problems strengthen both the methodological approach and the support for the more factual knowledge evidenced. For instance, the mixed research method on our pervasive game (Chapter 2) informed the data collection matrix of the ethnographic study (Chapter 3). Similarly, the development of a replay tool to analyze the quantitative data (position logs) of the game participants built the experience on handling digital footprints with fluctuating positioning quality. It helped to identify sources of uncertainty from patchy network connectivity that inspired the design of an algorithm that takes advantage of the cold spots in wireless coverage to detect mobility (Chapter 4). This approach was further explored with a design science research method through the analysis of different types of digital footprints generated during implicit and explicit human interactions with wireless infrastructures or mobile devices (Chapter 5 and 6). Across these case studies we have covered many aspects of explicit and implicit human interaction with ubiquitous information. We believe necessary to discuss the main aspects in this subsection.

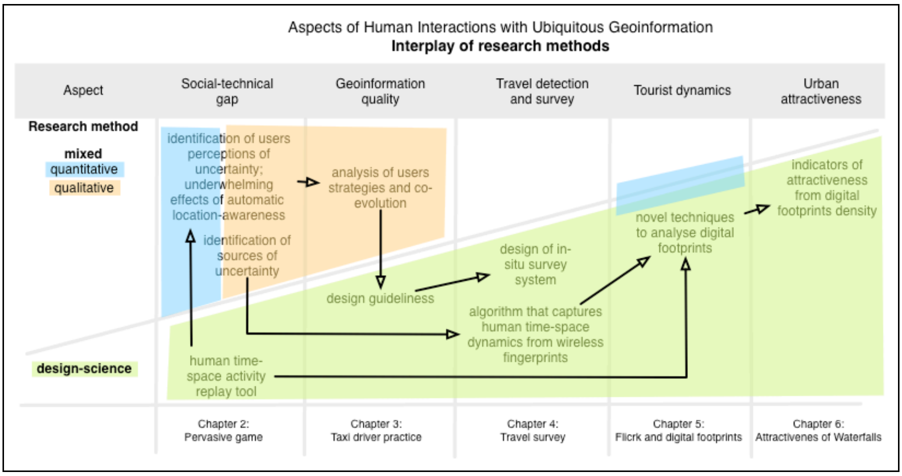

Figure 3. An interplay of research methods: the varied approaches applied to varied problems strengthen both the methodological approach and the support for the more factual knowledge.

Aspects of imperfections as the routine part of the convenience of computers

Although most people do not read the terms and conditions they agree to when using licensed software, they are willingly accepting an imperfect product whilst abrogating the supplier from responsibility for any damage caused. These imperfections in terms of bugs, glitches and crashes are at once notorious and yet also largely accepted as a routine part of the 'conveniences' of computers (Dodge et al., 2009)

We have seen that the fluctuating quality of the geoinformation people produce and handle plays a central role in their user experience. With the deployment of a pervasive game we could detect the sources of the imperfections from the supporting technologies and set some guidelines. More importantly, we could observe the players' reactions to spatial uncertainty (Chapter 2). We further analyzed this social-technical gap in real-world settings with taxi drivers when these reactions turned into strategies (Chapter 3). This presence of uncertainty impacts the learning process of the city that drivers sustain with an ecosystem of information sources. It also forces them to build skills to assess the quality of the geoinformation delivered by the in-car navigation system. These uncertain situations, that contradict the main purpose of the purchase of a navigation system to relieve drivers from their stress - made us propose the use of seamful design approach; an approach to reveal the state of the system rather than hiding it as proposed by others (Benford et al., 2005). We believe that these design guidelines promote the appropriation of technology and help reduce the social-technical gap generated by the limitation of technologies to produce the expected and humanly appropriate granularity of geoinformation. At this stage, these guidelines call for more empirical evidences. Taking into consideration the limitations of the technological settings is the source of another design solution as we demonstrated in our system that detects air travels from the full complexity of human and technological environments (Chapter 4). The emerging patterns of the data tend to reduce this perception of uncertainty as erroneous data get masked by the mass of valuable data (Chapter 5); this considering that the techniques to analyze the data (i.e. interpolation) do not distort the phenomena under observation (Chapter 6).

Aspects of clumsy automation

The massive amount of digital footprints is a manifestation of the increasing simplification and automation interactions with computers. For instance, our third case study (Chapter 4) that automated the air travel detection relied on the implicit interaction of mobile phones with the wireless infrastructure. However, over the years, the literature has discussed many examples of design errors of automating interactions (e.g. in aircraft cockpits, space mission control centers, and operating rooms; see for instance Woods, 1999). Our work suggests some dangers of, and solutions to "clumsy automation" in the context of ubiquitous geoinformation. In our third case study (Chapter 4), the travel detection algorithm did not completely remove the chance of false positives (i.e. the user has not taken the plane, but the algorithm detects a flight). In addition, the system requested the explicit consent of the traveler to communicate any information. These design measures were meant to respect the participant's privacy and keep him or her slightly aware of the survey. Indeed, applying a perfect algorithm might have an underwhelming effect on the involvement of participants completely forgetting about the survey. This insight was supported by our first and second case studies (Chapter 2 and 3) by showing evidences of the underwhelming effect of automating the disclosure of geinformation on collaboration, social interaction, and learning process of the environment. The alteration of the learning process does not necessarily imply that the integration of ubiquitous geoinformation has a deskilling effect. Indeed, users rely on other sources of information and social interactions when the automated process fails to deliver the expected quality of geoinformation. Finally, other aspects of human interaction with ubiquitous geoinformation can suffer from clumsy automation. We have discussed the richness in explicitly generated digital data as they hide intentions that bring a notion of subjectivity to the relation of people with space and place. This subjectivity is crucial to reveal tourist dynamics (Case study 4) or urban attractiveness (Case study 5).

Aspects of human-time relationships

The ubiquitous accessibility and generation of geoinformation ubiquitously creates an opportunity to infer or predict events in real-time as instantiated in the travel detection case study (Chapter 4). In addition, the ability to log interactions calls for the end of our ephemeral relation with space. Indeed, only a few years ago, the possibility to produce fully dynamic time-space diagrams from the fusion of human activities data and novel forms of geovisualization, was only discussed in the conditional. For instance Zook et al. (2004) mentioned:

When many individual diagrams are aggregated to the level of cities and regions, these visualizations may provide geographers, for the first time, with truly dynamic maps of dynamic human processes. One might imagine them as twenty-first century "weather maps" of social processes.

Our research work produced first instantiations of these possibilities. In practice, most case studies led us to develop algorithms based on interactions with wireless networks or the web to detect presence, mobility and flows (Chapters 2, 4, 5, 6). The logs of these interactions considered as digital shadows or digital footprints were fed to tools to replay space-time activity, to study location-awareness or air travel. The techniques, methods and tools to analyse user-generated spatio-temporal data and uncover novel viewpoints on the presence and movements of people during their visit of a city and the understanding of the evolution of the attractiveness of the space (Chapter 6). The cross-analysis of the data over weeks and months allowed to see that each type of log was representing different tourist dynamics (Chapter 5). This end of the ephemeral calls for new approaches to privacy issues. In consequence, each case study treating quantitative logs provided an approach to preserving individuals privacy such as the use of explicit disclosure of data in case of a relevant event (Chapter 4), the analysis of publically available georeferenced photos (Chapter 5), and aggregated cellular network traffic data (Chapter 6). Finally, our taxi driver study (Chapter 3) also sets stage to the end of the timelessness considerations of human interactions with ubiquitous geoinformation. Indeed, we observed how a satellite navigation system does not perform the same service the first six months in the practices of an inexperienced taxi driver compared to a user with 20 year of knowledge of the city. Moreover, these users do not, over time, request the same granularity of geoinformation nor they do assess the quality of the information with the same experience of the technology and knowledge of the city.

Aspects of human-space relationships

With the developments in digital communications technologies the access to geoinformation became ubiquitous and interactive. Maps are generated "on-the-fly" to meet particular needs (e.g., web mapping services, in-car navigation, and on-demand mapping to mobile devices) with a tailored view of the world centered on the user's location, changing the relations of people with the space. We have seen that it alters the learning process of the environment and social relations (Chapters 2 and 3). We hypothesized that the reasons of the presence of digital footprints has relation to the space they are georeferenced to. In response we explored that hypothesis first with the detection of air travel as the context. Then we also highlighted this relation with the semantic description of the space that helps reveal features of a space (e.g. the spatial presence of ruins in Rome with Flickr photos; Chapter 5). Finally, in the fifth case study (Chapter 6) we defined indicators that compare the evolution of the attractiveness and popularity of points of interests from the relative density of digital footprints confirming the hypothesis.

Evidences of the ubiquitous computing of the present

At a more abstract research level, these contributions bring evidences for a "ubicomp of the present" as claimed by Greenfield (2006), Bell and Dourish (2006) and Rogers (2006); with a conscience of the ubiquitous of today, its potentials, and its human and social implications - taking the messiness of everyday life as a central theme – seamful instead of seamless. Indeed, this "ubicomp of the present" is a massive decentralized agglomeration of the devices, connectivity and electricity means, applications, services, data and interfaces, as well as material objects such as cables, antennas and satellite navigation systems and support surfaces such as mobile phones that have emerged in an almost anarchist fashion, without a recognized set of guiding principles. This conditioned the unconventional and real-world aspect of our case studies that took stage on a university campus and cities (i.e. New York City, Rome, Florence, Barcelona). We led our research to unbeaten territories where administrative procedures were inexistent. In this context, liability and privacy issues are the obvious subjects that necessitate constant clear descriptions of the motivations, goals, data sets and methods used. This process requested to develop skills to communicate the value of the analysis for the present and the future to stakeholders, local authorities, journalists and citizens.

7.3. Implications for future research

From our initial work on collaborative location-based games (Chapter 2), the application field of our research has come closer to urban issues. Next, we discuss the implications of the contributions of this thesis framing further research on the integration of ubiquitous technologies into people's everyday lives in the urban context.

From hard to soft infrastructures

As suggested by the contributions of this thesis, in contemporary urban environments, it may not only matter how good the hard infrastructure is, it is the software infrastructure that also affects how individuals experience it. Software infrastructures are not only about technology, they are also about interaction designs, about taking into account the wider context of organization, systems and people, and even business models, legal and political contexts, belief systems and social and cultural fabric. If we do not understand these aspects, we are prone to make the same mistakes as those originated by past visions that relied on the fascination around the hard infrastructures and reducing cities to systems (Jacobs, 1961).

In this thesis, we have analyzed the potential weakness of soft infrastructures, which are not free from the social technical gap. Uncertainty – granularity - in the sensed data plays a role in the gap. This opens all sorts of doors regarding sampling density, standardization, quality control, power, control, officiality of data, update frequency (freshness), discovery mechanisms, ontologies and so on. The problem is not only with user-contributed data: its accuracy has been one of the big "gremlins' often overlooked in Geography; just because data come from an official source and has official metadata does not mean that it is accurate or updated. In consequence, when these data are wrong or controversial the repercussions can be huge. The Geographic Information Systems (GIS) field has a long history of tackling it and has created standards such as the "National Standard for Spatial Data Accuracy" as part of the official Federal Geographic Data Committee (FGDC) metadata. While these standards worked for dealing with data accuracy in traditional GIS, are they sufficient or appropriate for the user-generated data we explored in this thesis?

One source of solution might come from the user-generated data themselves. OpenStreetMaps[23] has made a strong case for "crowdsourcing" creating more accurate and timely maps (if not more complete) than traditional GIS approaches. Is there potential in using crowdsourcing to make all geographic data more accurate and timely? For instance, in Clickworkers[24], the National Aeronautics and Space Administration (NASA) relies on human perception and common sense to identify craters on Mars. OpenStreetMaps has presented an approach for increasing the timeliness and relevance of geographic data, but the commercial data providers often fail in this approach, to the current exception of TomTom Map Share[25] that thrives in its users community to correct the geographic information. Further study on the sustainability of these solutions will be necessary.

However, even if the data become perfect and accurate, the digitization of the world thus far is coarse, leading to gaps and pixelation. As we fill in those gaps through models and assumptions we blur certain details, while artifacts of the process are categorized as anomalies. In geographic information systems, this gray area is referred to as "uncertainty" and is not often reflected in users representations such as maps. According to our approach, we should find ways of following the opposite strategy, providing seamful representation to users. Following our argumentation line, it seems that the improvement of the relationships between hard and soft infrastructures should come with engaging the actors. We see using visualization as one way to stretch the imagination of the users and engage them into action. Some promising contemporary projects of exploitation of these soft infrastructures aim at revealing in real-time the invisible urban activity (Ratti et al., 2006) and return this information back to the people, forming a feedback loop (Calabrese et al., 2008).

Replay the city

The presence of the soft infrastructure and its logging capabilities implies that we are at the end of the ephemeral; in some ways we

---

[23] http://www.openstreetmap.org/
[24] http://clickworkers.arc.nasa.gov/
[25] http://www.tomtom.com/page/mapshare

have new means to replay the city. This potential to replay the city echoes very well with the recent interest of urban planners and designers in unconventional data sources[26]. Currently land use and space activity data are mainly collected through very traditional means with people paid to perform manual count. These non-longitudinal data limit the emergence of evidences from the statistical relations with variables (e.g. What is the effect of physical layout on movement? How do people use the space?). With the increasing availability of soft infrastructure the process of data collection is improved. For instance, it allows to better model time, space, and behavior as investigated in the domain of Geosimulation (Beneson and Torrens, 2004). In contrast, we are also ahead of conflicts to reveal or hide unwanted evidences, when new data can be used to the detriment of some stakeholders.

Nevertheless, the aim is to shift the urban design and planning practices from the speculative predictions and accommodation to more factual observations and improvements. Besides our work on urban attractiveness indicators, other research groups have been using a reality mining approach to derive specific characteristics of urban dynamics (Kostakos et al., 2008). A major challenge in this type of approaches is to draw a clear understanding of the boundaries and biases of the data. For instance not to confuse behaviors with endorsement, that can be considered as a limitation of our fifth case study (Chapter 6) which used the density of digital footprints as indicators of urban attractiveness. Therefore, future studies will need to rely on calibrations with ground truth information produced with proven techniques.

From data-driven urbanism to human/data-based urbanism

This ability to replay the city shows that there are opportunities for researchers to propose novel ways to describe the urban environment. However, there is a big assumption in seeing the world as consisting of bits of data that can be processed into information that then will naturally yield some value to people. It would lead to what we would call data-driven urbanism, as if urbanism could be driven by data. Indeed, the understanding of a

---

[26] Insights from a presentation given by Noah Raford (Director of Space Syntax): http://liftlab.com/think/fabien/2008/06/02/technology-people-place-and-space/

city goes beyond logging machine states and events. In consequence, let us not confuse the development of novel maps from previously uncollectable and inaccessible data with the possibility to produce “intelligent maps” [27]. Our work precisely draws some critical considerations on the current state of the art. At this stage we are still trying to figure out: 1) What parts of reality the data reveal? 2. What we can do with them? 3. How to communicate them to people for acquiring information (still a far stretch from “intelligent”).

Taken this caution into account, the application of our research approaches seem promising to gain knowledge on the presence and flows of human at a specific space (e.g. Lower Manhatan in New York) and with particular technologies (location-aware system in CatchBob! and satellite navigation system of taxi drivers in Barcelona) leading to an approach we would coin as “human/data-based urbanism”. It could consist in the use of:

The qualitative analysis to inform the quantitative queries: This approach first focuses on people and their practices, without the assumption that something computational or data process is meant to fall out from that. This qualitative angle can then inform a quantitative analysis to generate more empirical evidences of a specific human behavior or pattern. A few approaches in that domain address this perspective. Williams et al (2008) for instance argue that our understanding of the city could benefit from a situated analysis of individual experiences within cities, rather than taking particular urban forms as a starting point for the study of urban experience.

The quantitative data mining to inform the qualitative enquiries: In that approach, the quantitative data help to reveal the emerging and abnormal behaviors, mainly raising questions. The qualitative angle then can help explaining phenomenon in situation. The qualitative approaches actually requests to ask the right questions to learn anything meaningful about a situation.

---

[27] In response to Kazys Varnelis and Leah Meisterlin essay “The invisible city: Design in the age of intelligent maps”: http://liftlab.com/think/fabien/2008/07/19/the-data-driven-urban-computing/

An example of the latter could have been applied to the context of the impact of the New York City Waterfalls (Chapter 6). We used digital footprints to reveal the variations in spatial presence and abnormal patterns of temporal presence over the course of a 2 years period. In addition to this quantitative analysis we could have performed qualitative observation on the detected areas to reveal how the attractiveness evolves (e.g. Do people stay longer?).

This fosters the need for research and practitioners to develop a coherent understanding of the traces of the activity: both qualitative (e.g. audio and video recordings of action and interviews) and quantitative (e,g. logfiles). With significant data on actual use of the space, we can perform new types of "Post-Occupancy Evaluations" often overlooked in the practice of urban design and architecture (Brand, 1995). For example, Hill and Wilson (2008) propose multiple perspectives in analyzing the spatial usage patterns in a post-occupancy evaluation of wireless services in public buildings. It implies the collection of photo-essays, videos and in-depth interviews with users, and relating to this idea of making the invisible, visible. As a result, looking at usage patterns from various quantitative and qualitative perspectives, some analysis can be performed on how the variability of wi-fi maps onto the informal use of space enabled by the design of the space (see also Sevtsuk et al., 2007 for this approach). The objective of this methodology is not only to perform subsequent adaptations on the design object but also to reuse the lessons learned as input of other projects. However, the tools, metrics and interpretation methods are still, for a major part, to be developed.

Ethical issues and privacy concerns

Ubiquitous geoinformation are both immensely empowering (for the people and places able to construct and consume them) and potentially overpowering as institutional and state forces are able to better harness information with growing personal and spatial specificity. In consequence there are ethical and privacy implications to grapple with. In conjunction with people's own representation of traceability, there is a legitimate concern on the derive of research on geographically-anchored digital footprints presented in this thesis. Current debates crystallize around the issues of gathering data from people without their knowledge and the risk to reveal individuals from aggregated sensor data (Gutman and Stern, 2007).

We differentiate ourselves from the approaches that rely on the deployment of ad-hoc sensor infrastructures. First, our research innovates within EU directives[28] with on one hand anonymized, aggregated or publicly available data (Chapters 5 and 6), and on the other hand with the ability for the individual to opt out and refuse the transmission of private information (Chapter 4). Second, we apply the results to the context of cities services (e.g. tourism) and develop tools and techniques for the interests of citizens and visitors. Of course it implies revealing information that might not be of primary benefit of each individual who contributes to a census. Indeed, some of this information can challenge political decisions that were previously taken based on assumptions or limited survey data. For instance it might lead to a decrease in the offering of public transport in an unjustifiably well-connected neighborhood.

Therefore, our scientific contribution that provides an understanding of the potentials of digital footprints analysis, also contributes to the debate on ethical issues and privacy concerns. There are emerging initiatives on ethical guidelines for user experience in ubiquitous computing settings (Greenfield, 2008). This further proves the need for open discussions about the implications of these things considering a societal shift from a centralized “Big Brother” to distributed “bottom-up” surveillance (Batty 2003). Indeed, our work exemplifies the shift from large-scale top-down big brother thread on privacy issues to more local bottom-up little sister types of people monitoring, which makes the whole notion of opting out of technology adoption one of whether to opt out of society”

That being said, there have been numerous studies in the past that focused on “counting” people and measuring flows. It is interesting to note that it is not the first time that researchers and practitioners are looking at intimate part of city dwellers’ lives. For example, the use of trash content analysis executed in Geodemographics (Harris et al., 2005, pp 231-232) seems to raise fewer concerns, although it

[28] particularly the 2002 Directive of the European Parliament and Council on Privacy

can also be invasive. In other domains, there is an ever growing number of personalized records which are being collected, and at times disseminated in the databases and customer management systems of businesses, organizations, and government agencies that service modern living. In fact, these digital footprints have become inevitable in contemporary society and also necessary if we wish to enjoy many modern conveniences; we can no more be separated from it than we could be separated from the physical shadow cast by our body on a sunny day (Zook et al., 2004). The growth of our data shadows is an ambiguous process, with varying levels of individual concern and the voluntarily trading of privacy for convenience in many cases.

In summary, at the same time as ubiquitous geoinformation gives us new means to map and model human dynamics, it will also challenge current notions of privacy and make the object of study much more fragmented, dynamic, and chaotic. The challenge will be to appreciate and use the complexity and richness of ubiquitous geofinformation without crystallizing into authoritarian structures.

7.4. Concluding remarks

The emergence of ubiquitous geoinformation, as explored in this thesis, coupled with the considerable progress in the field of GIS, currently places us on the verge of a revolution in human time-space activity research (Shoval, 2007). Our work contributes to this evolution in creating a clear cut with respect to the existing remote sensing, arguing that human sensing enables to sense people directly, in contrast to remote sensing that applies more to the domain of physical geography. People-centric sensing adds a new layer of data to our digital earth (Goodchild, 2007) allowing us to understand it better through time and space. This complex layer is both challenging our capacity to make sense of the data collected and the people's willingness (or unwillingness) to act as data collectors.

Research in that domain draws together researchers from a broad spectrum of academic communities, for example, from geography, urban (urban studies, urban planning) and technical ones (computer science, software design, human-computer interaction etc.). Moreover, it focuses attention on the opportunities and problems of such ubiquitous computing. Currently, “Urban Informatics” is not a research field but rather a set of intersecting practices and broader disciplines swirling around those practices. It focuses not so much on the technology, but rather on its implications for (human) city life: *Informatics with its implied reference to information systems and information studies, slightly shifts the attention away from the hardware and more towards the softer aspects of information exchange, communication and interaction, social networks and human knowledge* (Foth, 2008).

We understand this intersection with three main tendencies: understanding urban dynamics, understanding the integration of ubiquitous technologies in urban life, and designing technologies for people in the city. Others defined it as “*the integration of computing, sensing, and actuation technologies in everyday urban settings and lifestyles*“ (Kindberg et al., 2007) or “*the collection, classification, storage, retrieval, and dissemination of recorded knowledge of, relating to, characteristic of, or constituting a city*” (Foth, 2008).

A majority of the research done in one or several of these elements of “Urban Informatics” has been driven by a utilitarian perspective, that models the city as a system and then aims at improving its efficiency. The background work in that domain partly explains the lack of consideration of human and social realities. Without blaming computer and information scientists, engineers, architects, or urban designers, none of them are necessarily trained in assessing the implications of their interventions. Only recently the techno-deterministic approach has been challenged through the influence of designers (Greenfield and Shepard, 2008), social scientists (Anne Galloway, 2008), and geographers (Hubbard 2006; Crang and Graham (2007)). Their influence generates the emergence of a new language that computer scientists and experts of the built space can integrate in their research and work, forging transdisciplinary practices. In consequence, it is noticeable that now social considerations go beyond privacy issues and touches the domains of the user experience, the impact of the research (e.g. positive change of practices) and the design for its appropriation (e.g. how to integrate into citizen daily life or a city administrative decision process). This language could also influence another layer of practitioners: the one mostly concerned with the problems of those who rule space or those who want to change policies (e.g. associations, street corner lobbies, public institutions, think tanks). These people are more concerned by change (social change) and the use of technology to go beyond current practices.

Therefore, beyond a utilitarian perspective, we have to consider the promises and hopes around these future cities and their informational membranes. If researchers and practitioners offer citizen better awareness of the city dynamics and power to influence the city evolution, this does not mean they will accept the gift. Indeed, taking the example of citizen-science (Paulos et al., 2008) and volunteer-generated information (Goodchild, 2007), citizens might just not be interested in the collection of data, and the opportunity might increase the divide between the people who are able to participate and those who are not or do not.

Throughout our work, we have shown that for every enabling technology we embrace, we should require ourselves to consider their implications and the strategies individuals and designers develop to appropriate them. Indeed, technological force and social counter-force technology pushers too often fail to recognize the difference between solving a problem and contributing to the health of society (Talbott, 2000). When failing to notice the messiness of everyday life, the design of a technical device or procedure can solve problem X while worsening an underlying condition much more serious than X.

Bibliography

Ackerman, M. S. (2000). The intellectual challenge of CSCW: The gap between social requirements and technical feasibility. Human-Computer Interaction, 15(2/3):181–203.

Batty, M. (2003). The next big thing: surveillance from the ground up. *Environment and Planning B: Planning and Design*, 30(3):325–326.

Bell, G. and Dourish, P. (2006). Yesterday's tomorrows: Notes on ubiquitous computing's dominant vision. *Personal and Ubiquitous Computing*.

Benenson, I. and Torrens, P. (2004). *Geosimulation: Automata-based* modeling of urban phenomena. Wiley.

Benford, S., Schnädelbach, H., Koleva, B., Anastasi, R., Greenhalgh, C., Rodden, T., Green, J., Ghali, A., Pridmore, T. P., Gaver, B., Boucher, A., Walker, B., Pennington, S., Schmidt, A., Gellersen, H., and Steed, A. (2005). Expected, sensed, and desired: A framework for designing sensing-based interaction. ACM Trans. *Comput.-Hum. Interact*. 12(1):3–30.

Brand, S. (1995). How Buildings Learn: What Happens After They're Built. Penguin.

Calabrese, F., Kloeckl, K., and Ratti, C. (2008). Handbook of Research on *Urban Informatics: The Practice and Promise of the Real-Time City*, chapter WikiCity: Real-time Location-sensitive Tools for the City. Hershey.

Craglia, M., Goodchild, M., Annoni, A., Camara, G., Gould, M., Kuhn, W., Mark, D., Masser, I., Maguire, D., Liang, S., and Parsons, E. (2008). Next-generation digital earth. a position paper from the vespucci initiative for the advancement of geographic information science. *International Journal of Spatial Data Infrastructure Research*, 3:146–167.

Crang, M. and Graham, S. (2007). Sentient cities ambient intelligence and the politics of urban space. *Information, Communication & Society,* 10(6):789–817.

Davies, N., Landay, J., Hudson, S., and Schmidt, A. (2005). Guest editors' introduction: Rapid prototyping for ubiquitous computing. Pervasive Computing, IEEE, 4(4):15– 17.

Dodge, M., Kitchin, R., and Zook, M. (2009). How does software make space? exploring some geographical dimensions of pervasive computing and software studies. *Environment and Planning A*.

Foth, M. (2008). Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City. Hershey, PA, IGI Global.

Girardin, F. (2007). Towards reducing the social-technical gap in location-aware computing. Master's thesis, Universitat Pompeu Fabra.

Goodchild, M. F. (1997). Towards a geography of geographic information in a digital world. *Computers, environment and urban systems*, 25(6):377–391.

Goodchild, M. F. (2007). Citizens as voluntary sensors: Spatial data infrastructure in the world of web 2.0. *International Journal of Spatial Data Infrastructures Research*, 2:24–32.

Greenfield, A. (2006). *Everyware*. New Riders Publishing.

Greenfield, A. (2008). Some guidelines for the ethical development of ubiquitous computing. *Phil. Trans. R. Soc. A*, 366:3823–3831.

Greenfield, A. and Shepard, M. (2008). *Urban Computing and its discontents*. Architectural League of New York.

Harris, R., Sleight, P., and Webber, R. (2005). *Geodemographics, GIS and Neighbourhood Targeting*. Wiley.

Hill, D. and Wilson, D. (2008). The new well-tempered environment: Tuning buildings and cities. In *Pervasive Persuasive Technology and Environmental Sustainability*.

Hubbard, P. (2006). *City*. New York, NY : Routledge,.

Jacobs, J. (1961). *The death and life of great american cities*. New York, Random House: 1961.

Kindberg, T., Chalmers, M., and Paulos, E. (2007). Guest editors' introduction: Urban computing. *IEEE Pervasive Computing*, 6(3):18–20.

Kostakos, V., Nicolai, T., Yoneki, E., O'neill, E., Kenn, H., and Crowcroft, J. (2008). Understanding and measuring the urban pervasive infrastructure. *Personal and Ubiquitous Computing*.

Latour, B. (2007). Beware, your imagination leaves digital traces. Times *Higher Education Supplement*.

Microsoft (2008). Being human: Human-computer interaction in the year 2020. Technical report, Microsoft Research Ltd, Cambridge.

Morrison, A., Tennent, P., and Chalmers, M. (2006). Coordinated visualisation of video and system log data. In *CMV '06: Proceedings of the Fourth International Conference on Coordinated & Multiple Views* *in Exploratory Visualization*, pages 91–102, Washington, DC, USA. IEEE Computer Society.

Nova, N., Girardin, F., and Dillenbourg, P. (2006). The underwhelming effects of automatic location-awareness on collaboration in a pervasive game. In *International Conference on the Design of Cooperative Systems*.

Nova, N. and Girardin, F. (2009). Framing the Issues for the Design of Location-Based Games, chapter *Digital Cityscapes: Mergining digital and urban playspaces*. Peter Lang Publishers

Paulos, E., Honicky, R., and Hooker, B. (2008). *Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City*, chapter Citizen Science: Enabling Participatory Urbanism. Hershey.

Ratti, C., Pulselli, R. M., Williams, S., and Frenchman, D. (2006). Mobile landscapes: Using location data from cell-phones for urban analysis. *Environment and Planning B: Planning and Design*, 33(5):727 – 748.

Rogers, Y. (2006). Moving on from Weiser's vision of calm computing: Engaging ubicomp experiences. In *Ubicomp*, pages 404–421.

Shoval, N. (2007). Sensing human society. *Environment and Planning B:* Planning and Design, 34:191–195.

Suchman, L. (1987). *Plans and Situated Actions. The Problem of Human-Machine Communication*. Cambridge Univ. Press, Cambridge.

Talbott, S. (2000). The trouble with ubiquitous technology pushers. In CFP '00: Proceedings of the tenth conference on Computers, freedom *and privacy*, pages 107–113, New York, NY, USA. ACM.

Townsend, A. (2008). Augmenting public space and authoring public art: The role of locative media. *artnodes*, 8.

Williams, A., Robles, E., and Dourish, P. (2008). *Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City*, chapter Urbane-ing the City: Examining and Refining the Assumptions Behind Urban Informatics. Hershey, PA: Information Science Reference, IGI Global.

Woods, D. D. (1997). Human-centered software agents: Lessons from clumsy automation. *Human centered systems: Information, interactivity, and intelligence*, pages 288–293.

Zook, M., Dodge, M., Aoyama, Y., and Townsend, A. (2004). New digital geographies: Information, communication, and place. *Geography and Technology*, pages 155–176.