Location-based technologies for learning

November 2008

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About the author

Steve Benford is Professor of Collaborative Computing and a founder of the Mixed Reality Laboratory at the University of Nottingham. His research explores advanced interaction and communication techniques for rich and dynamic social interaction, with a focus on the application of ubiquitous computing, mixed reality, augmented reality and virtual reality to entertainment and learning. His work has been awarded the 2003 Prix Ars Electronica for Interactive Art, a CHI 2005 Best Paper award and the 2007 Nokia Mindtrek award for innovative applications of ubiquitous computing. He has also received four BAFTA nominations.

Introduction

Positioning systems such as GPS enable computers to detect where we are located on the planet and to respond with relevant information and guidance. This idea lies at the heart of ‘location-based computing’ in which computer users become unchained from their desktops and consoles to instead explore the physical world around them, a world that becomes richly populated with digital media. Early examples of location-based computing are already with us in the form of satellite navigation systems for drivers and now also for pedestrians, the latter delivered as services for GPS-enhanced mobile phones. These are just the beginning, however, and recent research projects have demonstrated the potential for location-based computing to underpin a variety of new experiences including tours, games and new forms of learning. Ultimately, location-based computing may lead to the creation of ‘mixed realities’ in which the virtual worlds of games, online social spaces and the internet are merged with the everyday physical world to create new physical-digital hybrids.

The emergence of location-based computing is underpinned by the increasing availability, sophistication and integration of mobile devices, wireless communications, location systems and geographical databases. Mobile devices range from traditional laptops and handheld computers to mobile phones and portable games consoles. These employ wireless communications such as mobile telephony (GSM, GPRS and now 3G), Wi-Fi and personal-area networking technologies such as Bluetooth. They also build on various forms of positioning service, including satellite-based systems such as GPS and its European successor Galileo that offer automated positioning when outdoors, to more localised approaches based on proximity to known Wi-Fi access points or Bluetooth beacons, through to highly localised approaches such as the use of radio frequency identification (RFID) tags and 2D bar codes. Finally, they use the resulting location information to index into spatial databases of information, ranging from local file stores of media to specialist geographical information systems and, more recently, online public services such as Google Earth. Whatever the particular combination of technologies in use, location-based applications build on these four key elements: devices, communications, location services and geographical databases.

Location-based computing has the potential to stimulate new forms of learning. It can place knowledge in context, associating digital resources with physical locations and artefacts during a field trip or as part of an everyday experience outside of the school boundary. It can enable learners to document the world around them, capturing images, videos and measurements that are then ‘geo-tagged’, that is, associated with physical locations so that they can be readily analysed and compared. Then there is the potential to support new forms of collaborative learning, from publishing and sharing captured data using geographical databases, to enabling remote participants to piggyback on the experience of others as they explore a physical environment.

However, the combination of learning and location-based computing also raises significant challenges. There are privacy and security concerns surrounding interaction in public settings and the sharing of personal location data. There are also serious technical challenges arising from limitations in the underlying technologies, including the limited coverage and accuracy of positioning and communications systems.

This article explores the synergy between location-based computing and learning, covering both the potential opportunities and challenges. It begins by reviewing recent examples of research projects, focusing on the three areas of: visits, field trips and participatory sensing; pervasive games; and sport, health and biosensing. It then considers some key design challenges for location-aware computing.

Visits, field trips and participatory sensing

Outside of satellite navigation systems, one of the earliest testing grounds for location-based computing has been the museum or gallery, environments that are concerned with public education and often also with more formal education through school field trips. From traditional guidebooks and tour guides, to today's audio tours in which visitors key in location codes or trigger infrared beacons, there is a long history of trying to provide commentary about artefacts, exhibits, artworks and sites of special interest in situ, that is, at the moment when the visitor is standing in front of them.

Recent research projects have explored how both indoor and outdoor positioning technologies might deepen the connection between physical artefacts and digital media. In the HIPS project, visitors to the Museo Civico in Siena received audio messages on their handheld devices that were related to the closest object.[1] The ARCHEOGUIDE project used see-through head-mounted displays to allow visitors to view reconstructions of missing artefacts and damaged surfaces at an ancient historical site.[2] In the Electronic Guidebook project, visitors to the Exploratorium in San Francisco scanned bar codes and RFID tags near objects of interest in order to access web pages about them on their handheld devices.[3] Projects such as these create so-called 'mediascapes' in which digital media such as text, images, sounds and videos appear to be attached to locations in the everyday world. These media might be professionally authored, but might also be user-generated (for example, with people leaving their own text and photos as 'digital graffiti' attached to a location).

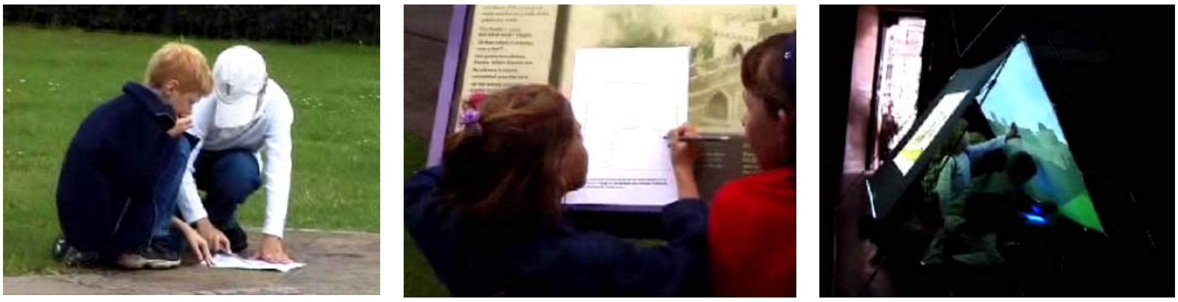
Some projects have considered how location-based technologies might transform the visiting experience in more radical ways. The Equator project explored the issue of co-visiting in which local 'physical' visitors to The Lighthouse in Glasgow were tracked using ultrasonic positioning as they explored a gallery and how this enabled them to compare perspectives with remote 'online' visitors, one browsing information on the web and a second exploring a 3D virtual model of the gallery.[4] In contrast, the Shape project explored the creation of coherent experiences for groups of visitors as they explored a site of special interest, Nottingham's historic castle, over several hours (see below). Shape used electronically tagged pieces of paper to connect together different aspects of the overall visiting experience including exploring the physical site, making drawings and notes, and then relating these back to interactive installations that revealed further information.[5]

The Shape project

Nottingham Castle has been home to over 1,000 years of British history, including the exploits of Robin Hood and his followers. However, visitors to the current castle face a difficult challenge: how to understand the many interleaved events that have taken place at different times and locations, in buildings and spaces which in many cases no longer exist. The Shape project, funded under the European Commission's Disappearing Computer programme, addressed this problem by creating a 'history hunt' around the castle grounds.

Groups of visitors, families and school parties collected a set of paper clues that led them in search of a particular historical figure, for example, Richard the Lionheart. At key locations associated with this person, they were required to annotate and personalise the paper, for example, making rubbings or drawings. Back inside the museum, they then used their completed paper clues, which were electronically tagged using RFID tags, to drive their interaction with several installations that revealed further information. The Storytent was a projection screen folded into the shape of an A-frame tent so as to create a mini immersive environment for experiencing virtual worlds. Visitors placed paper clues on a turntable, which through an embedded RFID reader triggered the display of a 3D historical reconstruction that was associated with their clue. They could rotate the turntable to view a 3D panorama and also view related paintings and documents from the museum's collection. A second installation, the Sandpit, was a floor-projected display of graphically simulated sand in which groups of visitors could 'dig' for images.

The core idea behind this project is that the familiar medium of paper can be electronically enhanced to provide the connections between physical artefacts and locations and specialised installations as part of an extended educational experience. Visitors could easily create and annotate their own paper clues that then served to connect together the different physical and virtual parts of the experience, and could also be taken away with them afterwards as souvenirs or perhaps to display back in the classroom.



Images from the Shape Living Exhibition: Making a paper clue as a 'rubbing' (left), annotating a paper clue (middle), and using the clues to trigger the exploration of stories in the Storytent (right)

Other landmark projects have explored the use of location-based technologies to support educational field trip activities, often with an ecological or scientific theme, including Ambient Wood, in which students explored the ecology of a woodland, and Mudlarking in Deptford, in which they explored the environment of an estuary.[6, 7]

The use of location-based technologies to support scientific education extends to the approach of participatory sensing, capturing scientific measurements from the environment using specialised sensors that are then annotated and also geo-referenced using a positioning technology such as GPS so they can be analysed and compared back in the classroom. The Sense project integrated mobile carbon monoxide sensors with GPS so that groups of students could study air pollution in the local environment around their school, a theme that was further developed in the Participate project, in which multiple schools generated trials of air and noise pollution readings on journeys to and from school that could then be reviewed and compared using Google Earth.[8, 9]

Pervasive games

Recent years have seen a growing interest in the use of location-based technologies to create new forms of pervasive games in which the virtual worlds of computer games become increasingly enmeshed with the everyday world around us.[10] Early examples of such games have explored a wide variety of forms and genres.

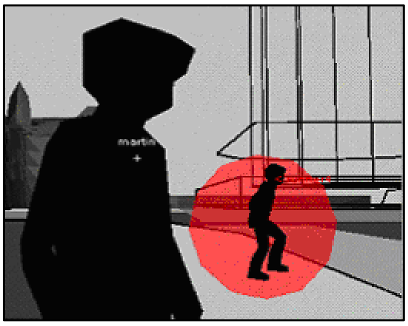
Some examples have reinterpreted classic computer games for the city streets. ARQuake (the augmented reality version of Quake) employed a combination of GPS positioning, wireless networking and see-through head-mounted displays to overlay the 3D virtual world of Quake onto an actual urban environment so that virtual characters and players would seem to be moving through the city streets.[11] The Human Pacman project extended the well-known game Pacman by enabling remote online players to interact with those on the city streets.[12]

This idea of connecting online and ‘street’ players has perhaps best been explored by the artists Blast Theory as part of a series of touring artistic games. Can You See Me Now? was a game of chase in which street players ran through a real city in order to catch online players in a parallel online virtual model of that city.[13] Uncle Roy All Around You involved online and street players exchanging messages and collaborating to follow location-based clues as they navigated the city in search of an elusive character called Uncle Roy.[14]

Can You See Me Now?

Can You See Me Now? was a game of chase, but with a twist. Street players, equipped with handheld computers, ran through the streets of a city. GPS tracked their location and this was transmitted to a game server over a wireless network which used it to update the position of their avatar in a 3D model of the city. Up to 20 online players could log in over the internet and move their avatars around the model, with their positions being sent back to the street players and displayed on a map on their handheld computers. The street players then had to run through the actual city to get their avatar to chase the online players in the virtual city. If they got close enough, then they were caught and out of the game.

As they ran, street players discussed their tactics and the city – for example, its hills, buildings, weather and traffic – over walkie-talkies and this was streamed to the online players. In this way, online players could tune in to the experience of the remote street players, sharing their perspective of the city and leading them a merry dance.



Can You See me Now?: The physical world and the virtual world (the street player's avatar is circled in red)

Other examples adopt a subtly different emphasis, focusing on how location-based and other technologies can help enhance and better co-ordinate traditional physical gaming activities. A popular pastime for some is geocaching, in which people hide physical objects and then publish their coordinates so that others can find them.[15] Other examples are provided by alternative reality games (ARGs), in which masses of players take part in extended treasure hunts and similar activities and in which the world of the game is interwoven with everyday activities so that the two may often become blurred.[16] In a similar vein, live action role plays (LARPs) can also be enhanced with technology so as to create different forms of 'magic' or help co-ordinate distributed activity.[17] In these examples, the technology fades more into the background and the boundary between game and reality becomes more blurred.

A further possibility is to consider the use of mobile phones to create games that can be played casually in the downtime between activities, for example, while on the move. One of the earliest commercial mobile phone games, BotFighters!, used 'cellular positioning' – that is, using signal strengths from mobile phone masts to triangulate players' locations – to help players battle on the streets. Alternatively, Day of the Figurines, another product from Blast Theory, enabled players to use text messaging to engage in a text-based adventure game.[18] Day of the Figurines was deliberately designed to be a slow game that could be played episodically over a month by sending and receiving just a few messages each day and so be interwoven with the patterns of players' daily lives.

Finally, the growing interest in serious games, including their potential for learning, has also spread to pervasive games and there have been several examples of pervasive games that address educational themes.[19] The Savannah project, a collaboration between Futurelab, HP, the BBC and the Universities of Nottingham and Bristol, transformed a school playing field into a virtual savannah so that groups of students could learn about the behaviour of lions trough active role play.[20] Six students at a time would explore the playing field using handheld computers with GPS and Wi-Fi to hunt virtual animals. They would then debrief back in a 'den' in the classroom, replaying their movements and actions on an interactive whiteboard in order to review and discuss their tactics in comparison to those of real lions. Futurelab and Nottingham's Mobimissions project (see below) explored the potential of mobile phones to support casual learning by enabling players to undertake missions within the world around them.[21]

Mobimissions

In Mobimissions, players used their camera phones to set short missions for one another, search locations for local missions to try out, and document their attempts at missions for others to see. The missions were created by the players themselves and consisted of a series of up to five text instructions and images, for example, asking players to give opinions about their daily lives, find things and locations of interest, or even improvise a short public activity or tour.

Using cellular positioning, missions could be associated with locations. Players would search their current location to see if any missions were available. They could then 'pick up' a mission and carry it around on their phone until they had a chance to complete it, before dropping it off again at a new location for other players to find. In this way, missions would move from location to location and player to player as the game progressed.

Players would document their attempt at a mission by generating up to five images along with text messages and these would be loaded onto the game website for the mission creator and other players to view. Players could rate and comment on mission attempts and also on the missions themselves and scored points for the missions that they created.

The mobile phone interface for Mobimissions: Available missions at this location (left), the instructions for a specific mission (middle), and a player's response (right)

Sport, health and biosensing

Related to pervasive games is a growing interest in using location-based (and related) technologies to encourage health, fitness and sports-related activities. Sensing technologies such as pedometers are already routinely used by runners and are beginning to be embedded into sports clothing and accessories. Cyclists, too, have adopted similar technologies, ranging from simple speedometers and GPS navigation devices to systems designed for serious athletes which record variables such as pedal power, road incline and heart rate and graph them later on a computer. Moreover, general-purpose devices with GPS capabilities such as mobile phones and PDAs have been repurposed by cyclists for tracking performance and for navigation; several websites have emerged to support the sharing and rating of bike routes that are recorded using these units (for example, MapMyRide – http://www.mapmyride.com and Bikely – http://www.bikely.com).

There have also been several recent research projects that have explored a (broadly interpreted) health, fitness and physiology agenda by combining different physiological sensors with location-aware technologies. The 'Ere Be Dragons (now known as Heartlands) project from the artists Active Ingredient (see below) extended previous examples of pervasive gaming to also include an element of fitness, using both GPS and wearable heart-rate monitors to control players' interactions.[22] Futurelab's Fizzies project on physical electronic energisers combined heart-rate sensors and accelerometers with a wrist-worn display to promote healthy activity by requiring children to engage in physical exercise in order to nurture a wrist-worn digital pet.[23]

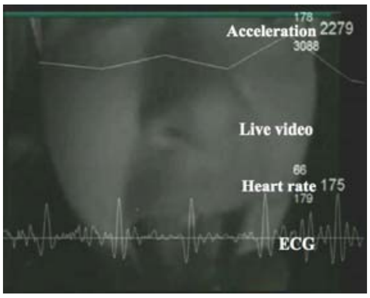
Heartlands

Armed with handheld computers with GPS and wireless networking but also with heart-rate monitors that were attached to their torsos, players had to move through the city to capture territory, competing against the clock and against others to see how much they could gain. The twist in the game was that the captured territory depended on both location (the player has to find unclaimed areas of the city) and also physical state (if the heart rate was too low or too high, then the wrong kind of territory would be generated). Players, therefore, had to maintain themselves in the right physical 'zone' as they played, sometimes running and sometimes resting in an attempt to control their heart rates. Back at base, spectators could monitor their progress on a large public display.

Other projects have considered how physiological sensing can enable reflection on one's emotional response to an environment or experience. The artist Christian Nold has undertaken a series of biomapping projects, capturing a combination of GPS and galvanic skin response (GSR) measurements (changes in the skin's resistance that may be associated with anxiety or arousal) as people journey around a city and presenting this information back to them to provoke reflection on their reaction to different aspects of the environment, an approach that has since been adopted by urban planners for public consultations.[24] Turning to a quite different kind of experience, the artist Brendan Walker has used wearable biosensors combined with acceleration data to explore the experience of amusement rides (see below).[25]

Fairground: Thrill Laboratory

The Fairground: Thrill Laboratory project is exploring the experience of thrill by instrumenting passengers on high-intensity amusement rides. Each rider wears a personal telemetry system that captures video (close-ups of their facial expression) and audio (as they talk and scream!), heart rate and GSR data, and movement data from an accelerometer. This data may be streamed live to watching spectators or recorded to be shown to the riders afterwards, and in both cases is accompanied by an expert interpretation that explores the relationship between the psychological experience of thrill in terms of concepts such as valence (is it a good or a bad feeling) and arousal (how strong is the feeling) and physiological response.



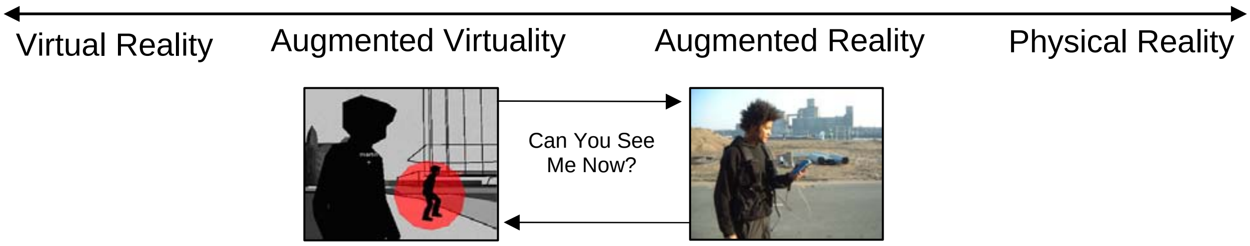
Images from Fairground: Thrill Laboratory at Alton Towers theme park: Riding Oblivion, the world's first vertical drop rollercoaster (left), a close-up of the riders and their equipment (middle), and a visualisation showing captured video overlaid with physiological data (right)

Although pervasive games and amusement rides may seem quite a long way removed from learning, projects such as these demonstrate the potential of a combination of location-based technologies and physiological sensing to provoke reflection on fitness and emotional response, which could support new forms of learning. Indeed, this theme is currently being explored by the ongoing EPSRC/ESRC-funded Personal Inquiry project, which is investigating new forms of science inquiry learning in relation to the twin themes of the body and the environment.[26]

Interweaving the real and virtual

A distinctive feature of the experiences described above is the way in which they combine mobile location-aware computing with virtual worlds to create different kinds of 'mixed reality'. Milgram and Kishino have proposed that mixed reality involves a continuum of possible arrangements of the real and virtual (see diagram below).[27] At one extreme is the experience of everyday physical reality; at the other is pure virtual reality which immerses participants in computer-generated simulations. In between, lie various other possibilities including ‘augmented reality’, in which the physical world appears to be overlaid with a virtual one (for example, the ARQuake game mentioned previously), and ‘augmented virtuality’, in which virtual worlds are made live with streams of data from the real world.

Milgram and Kishino’s Mixed Reality Continuum



Several of our experiences occupy several points on this continuum simultaneously, combining forms of augmented reality and augmented virtuality into a single experience. For example, Can You See Me Now? and Uncle Roy All Around You involve street players who are experiencing a form of augmented reality communicating with online players who are experiencing augmented virtuality, creating what might be termed a kind of ‘hybrid reality’.

The mixing of real and virtual worlds to create these kinds of sophisticated hybrid structures is a major departure from today’s first generation of location-based services, such as navigation aids that focus on annotating the physical world with digital information. They also introduce new possibilities for learning. Augmenting the physical world enables mobile participants to learn in situ by exploring their environment, accessing digital resources in context at the moment of experience, and extending learning beyond the school boundary. Virtual worlds, on the other hand, support simulation, visualisation and fantasy, enabling people to comprehend and manipulate information in new ways. Combining the two may enable both forms of learning and also allows for remote collaboration between people with different perspectives on a situation.

There are other possibilities, too. Projects such as the Shape Living Exhibition, Ambient Wood and Savannah also have a hybrid structure, but this time participants experience the different perspectives in sequence, moving from exploration of an augmented physical world (the historic castle grounds, woodland or playing field) to exploration of virtual worlds (the Storytent and ‘den’) in order to further explore, reflect on and discuss what they found. In other words, learning experiences might use mobile and location-aware computing to interleave physical and virtual worlds in time as well as in space. The most extreme example of this temporal interleaving is Mobimissions, which exploits the nature of the mobile phone to create a highly episodic experience with participants rapidly dipping in and out of different modes (doing missions and then reviewing and rating them) at times and places that suit them.

Public interaction

Location-based experiences encourage exploration of the everyday world around us, potentially changing the nature of the way in which we engage with – and learn about – locations and artefacts. While this opens up the possibility for new forms of personalised and contextual learning that reach beyond the traditional classroom, it also raises significant new challenges.

One of these concerns is the increasingly public nature of interaction. Many location-based experiences will take place in public settings and so raise the potential for interactions with passers-by. In several of the experiences discussed above, some participants reported feelings of heightened visibility and even vulnerability, including the risk of having equipment stolen, although in practice this seems to be rare. In others, passers-by were intrigued by the participants' actions (as with the runners in Can You See Me Now?) or sometimes even became involved, for example, being asked for directions or help. Uncle Roy All Around You deliberately exploited the public nature of interaction to create mystery and suspense, for example, giving clues that implicated passers-by in the experience (at one point participants are asked to 'follow someone in a white T-shirt' who is approaching).

Experiences such as these point to the importance of framing, that is, the way in which the experience is introduced to participants and its boundaries and conventions established.[28] The framing of experiences in the classroom tends to be quite clear and follows a series of well-understood rules. The framing of location-based experiences on city streets, however, is quite different and requires careful attention. Experienced designers and providers must carefully consider the possibilities of interactions with members of the public. Strategies for dealing with these include briefing participants, designing routes that steer clear of dangerous areas (busy roads and other unsafe zones), and also ensuring a suitable level of orchestration, for example, having people who monitor participants' movements and actions and carefully intervene in case of any difficulties.

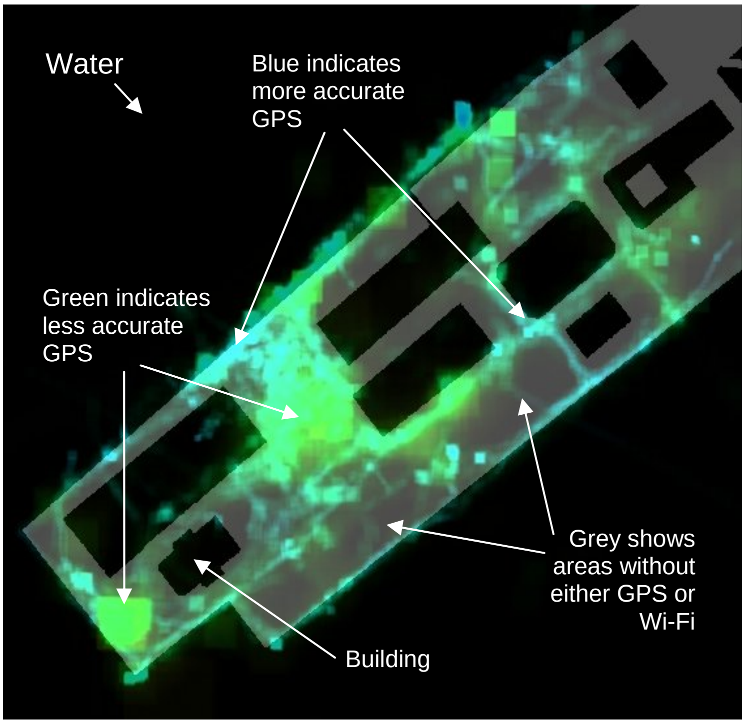
A further twist on the issue of public interaction concerns the capture and publication of movement trails. Participatory sensing projects such as Sense and Participate involved participants recording and sharing GPS trails of journeys, including journeys to and from school. A topic of concern and discussion in these projects has been the extent to which such data might be shared between schools or even more publicly as part of engaging 'big science' projects, the problem being that doing so potentially reveals details of where children live. Attention needs to be paid to whether, how and to whom such data is revealed. Revealing trails after a visit to a site of special interest may be fine, whereas revealing daily journeys to and from school may be far more sensitive.

Dealing with seams in the technical infrastructure

For our final theme we turn to the underlying technologies of location-aware computing. As noted previously, experiences such as those described above rely on multiple kinds of technology. First, there are devices of various kinds, including computational devices such as handheld computers, mobile phones, laptops and embedded computers, but also including the everyday artefacts to which they are attached including clothing, pieces of paper, furniture and vehicles. Second, there are the sensing technologies that determine location and possibly other aspects of the user's activity and context, ranging from more or less global systems such as GPS to local systems that can sense proximity to a particular marker or beacon, but also including environmental and physiological sensors to capture data from the environment and from participants' bodies. Then there are the networking technologies that transmit data between computers, sensors and remote servers and that connect them to the wider internet, again ranging from wide area mobile telephony services to more local technologies such as Wi-Fi and Bluetooth. Finally, there are geospatial databases that can store the information of interest.

These elements – devices, networks, sensors and databases – are then stitched together to create a location-aware experience, supported by software tools and middleware for authoring content, distributing data and orchestrating live experiences. For example, software tools such as Create-a-Scape enable users to create a location-aware experience by attaching digital assets to maps of the physical world, scripting triggers that will display these according to a user's location, and then downloading these to a device.[29]

And yet in practice, creating a successful experience may not always be so simple. The underlying technologies, especially sensing and wireless communications, often have inherent limitations in terms of their coverage and accuracy that can profoundly affect the user's experience. Many people entering this arena for the first time are surprised by the inherent limitations of GPS that sometimes appears to be far from an ideal global positioning system. As an example, consider the visualisation below that has been derived from over two hours of logged data from Can You See Me Now? when it was played in Rotterdam. This visualisation shows an aerial view looking down on a peninsular; the areas of black at the outside are water and the positions of the main buildings are also superimposed as black rectangles. Each spot of light in the image shows a position where a GPS reading was successfully captured and transmitted back to the game server over Wi-Fi. A small blue dot indicates that the GPS was accurate to a few metres according to its own estimate whereas a larger green blob shows a reported inaccuracy of 10 metres or more. However, the most striking feature of this image is all those areas where there is no colour. Although we observed that runners covered most of the peninsular, and especially the central streets between the main buildings, there were many locations with no reported positions. Either GPS could not obtain a reading (it is necessary for a GPS receiver to be able to see at least three satellites in the sky to be able to triangulate its position) or there was no Wi-Fi coverage or perhaps both. This lack of coverage is not an occasional glitch or bug in an experience, but rather is an ongoing persistent characteristic that makes location-based experiences fundamentally different from traditional computing experiences.



Visualisation of GPS/Wi-Fi coverage from Can You See Me Now?

What should the designers of location-based experiences do about these so-called ‘seams’ in the technical infrastructure.[30] Researchers have identified five possible strategies:[31]

- **Remove them** – develop and deploy better technologies (perhaps the new Galileo positioning system instead of GPS) or multiple technologies to ‘fill in the gaps’. However, it may still be difficult to achieve high coverage in built-up urban areas.

- **Hide them** – use techniques that hide the gaps in coverage, for example, predicting possible movements when people disappear from view as is the case with current satellite navigation systems. However, cars may be far more predictable than pedestrians.
- **Manage them** – carefully orchestrate experiences from behind the scenes to recover from problems and guide people as to where to go so that they get connected again. This was the approach adopted to make Can You See Me Now? work effectively.
- **Reveal them** – show designers and participants images like the above so that they can understand the behaviour of the infrastructure and so design more robust experiences. For example, we might overlay such data on the maps used by Create-a-Scape and similar tools so that authors can avoid placing assets in areas of poor coverage.
- **Exploit them** – finally, why not turn the problem on its head and turn the seams to one's advantage? Researchers have recently demonstrated a series of 'seamful games' in which limited coverage and accuracy become resources in the experience, for example, with players being able to hide in the GPS 'shadows'.[32] There are interesting educational possibilities here in which students might actively explore coverage and accuracy in order to learn about the nature of the underlying technology itself.

Conclusion

Today's navigation systems represent the first step towards the deployment of sophisticated location-aware experiences that interweave digital media and computation with the everyday physical world. The likely widespread adoption of location-based technologies over the coming decade, especially the integration of GPS into mobile phones and digital cameras, will drive the emergence of new location-aware services. In particular, the convergence of these location-enhanced mobile devices with geographical information systems and social software will underpin new services such as local searching for nearby facilities, finding and meeting friends, and location-tagged blogging. This convergence will also enable researchers and governments to capture, analyse and model patterns of movement of people and vehicles as part of the challenges of sustainable transportation or dealing with public security and the management of large events (for example, the 2012 London Olympics). However, such developments will also raise the profile of key societal issues including privacy, anonymity and trust, and these will need to be debated and addressed if such services are to gain widespread public acceptance.

Our review of recent research projects in this area has revealed the potential for creating a wide range of engaging location-aware experiences in areas such as field trips and participatory sensing, pervasive games, and sports and fitness applications. This review has also revealed how location-based experiences can involve sophisticated spatial and temporal structures that mix real and virtual spaces in different ways and emphasise episodic engagement within the patterns of daily life.

These kinds of experiences and structures offer tremendous potential for learning: extending learning beyond the boundaries of the classroom, engaging learners in context, enabling them to capture information from the wider world for subsequent study and reflection, and interweaving episodes of learning with other ongoing activities. However, it is also necessary to recognise the distinctive nature of location-aware experiences and to design them accordingly; designers need to take account of both the opportunities and risks surrounding interaction in public settings and also need to accommodate the impact of seams in the underlying technical infrastructure. Providing that these challenges can be met, then location-aware experiences, and their ultimate extension to fully ubiquitous computing in which computation is deeply and fully embedded into the everyday world, promise to transform the ways in which we live, work, play – and learn.

Acknowledgements

I am very grateful to my many collaborators for their work on the projects described in this report, including the artists Blast Theory (Can You See Me Now? and Uncle Roy All Around You), Brendan Walker (Fairground: Thrill Laboratory) and Active Ingredient (‘Ere Be Dragons/Heartlands), and Futurelab (Savannah and Mobimissions) and Nottingham Castle Museum (the Shape Living Exhibition). I would also like to acknowledge the support of the Engineering and Physical Sciences Research Council (EPSRC) through the Participate project (EPSRC grant EP/D033780/1, www.participateonline.co.uk).

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