Can You See Me Now?

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We present a study of a mobile mixed reality game called *Can You See Me Now?* in which online players are chased through a virtual model of a city by 'runners' (professional performers equipped with GPS and WiFi technologies) who have to run through the actual city streets in order to catch the players. We present an ethnographic study of the game as it toured through two different cities and draws upon video recordings of online players, runners, technical support crew, and also on system logs of text communication. Our study reveals the diverse ways in which online players experienced the uncertainties inherent in GPS and WiFi, including being mostly unaware of them, but sometimes seeing them as problems, or treating the as a designed feature of the game, and even occasionally exploiting them within gameplay. In contrast, the runners and technical crew were fully aware of these uncertainties and continually battled against them through an ongoing and distributed process of orchestration. As a result, we encourage designers to deal with such uncertainties as a fundamental characteristic of location-based experiences rather than treating them as exceptions or bugs that might be ironed out in the future. We argue that designers should explicitly consider four potential states of being of a mobile participant: connected and tracked, connected but not tracked, tracked but not connected, and neither connected nor tracked. We then introduce five strategies that might be used to deal with uncertainty in these different states for different kinds of participant: remove it, hide it, manage it, reveal it, and exploit it. Finally, we present proposals for new orchestration interfaces that reveal the 'seams' in the underlying technical infrastructure by visualizing the recent performance of GPS and WiFi and predicting the likely future performance of GPS.

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1. INTRODUCTION

Can You See Me Now? (CYSMN) is a game of catch—but with a twist. Online players are chased through a virtual model of a city by 'runners' or street players, who have to traverse the *actual* city streets in order to capture the online players. Up to fifteen members of the public at a time can be online players, accessing the virtual city model over the Internet. The four street players are professional performers who chase online players through the city streets using handheld computers with wireless network connections (using 802.11b—WiFi) and GPS receivers. The online players can move through the virtual model of the city at a fixed maximum speed, can access various views of the city streets, can see the positions of other players and the runners, and can exchange text messages with one another. As the runners move through the city streets they can see the positions of the online players and other runners on a handheld map, can see the players' text messages, and can communicate with one another using walkie-talkies. The runners' walkie-talkie communication is streamed to the players over the Internet, providing real time descriptions of the runners' actions and their experience of the city streets, including reports of traffic conditions, descriptions of local street scenes, discussions of tactics, and the sounds of the physical labour involved in tracking players down.

Location-based games such as CYSMN are an exciting commercial prospect, building directly on current wireless (but usually disconnected and location independent) games. Early examples of commercial location-based games include *Bot Fighters!* from Its Alive! (www.itsalive.com) and *Battlemachine* from UnwiredFactory (www.unwired factory.com). Research projects have also begun to explore the challenges involved in delivering location-based games on the streets, including *Pirates!* [Bjork et al. 2001], *AR Quake* [Piekarski and Thomas 2002], *Border Guards* [Satoh et al. 1998], and *Mindwarping* [Starner et al. 2000], demonstrating how different displays including handheld computers and see-through head-mounts can be combined with sensing systems such as GPS and video-tracking to create experimental gaming experiences. Not only do such projects offer glimpses of potential new applications for location-based technologies, but they also provide a useful vehicle for HCI research, especially for studying how participants experience location and context-sensing technologies and how they manage to coordinate distributed collaborative activities in spite of considerable technical uncertainty. Indeed, our general experience is that games are particularly appropriate applications for researching how people experience emerging technologies because they offer an open and flexible design space where researchers can test a variety of scenarios (both collaborative and competitive) and yet can be relatively easily and safely fielded to the public at events such as new media festivals, bringing end-users into contact with new technologies in a way that might not be so easy in commercially sensitive or safety-critical environments.

This article describes our experience of publicly deploying CYSMN, a mixed reality game that has emerged from collaboration between the artists' group Blast Theory and the Mixed Reality Laboratory. Not only is CYSMN a game, but it is also a professionally touring artwork (in the form of a game), which between 2001 and 2004, has toured several cities throughout Europe including Sheffied, Rotterdam, Oldenberg, Cologne, Brighton, and Barcelona, being hosted by various arts festivals and related cultural organizations along the way. From a research perspective, CYSMN therefore offers a valuable opportunity to study an innovative new application of location-based technologies that is both highly experimental and yet has also been fielded to thousands of public players and gradually honed and refined over a three year period. Our goals in creating and staging CYSMN were twofold.

- First, we wanted to create an engaging artistic experience that would also provide a compelling vision of future games and artistic applications.
- Second, we wished to learn from the practical experience of taking location-based technologies out of our laboratory and deploying them among large numbers of users in the most realistic and challenging situations that we could feasibly achieve.

Evidence that we met the first goal is given by a positive reaction from the public, press, and commissioning bodies (including bookings to tour the work to different cities) and, in particular, by the award of the 2003 Prix Ars Electronica Golden Nica for Interactive Art (www.aec.at/en/prix/winners2003.asp). This article focuses on the second goal and the issues raised and lessons learned for computer-human interaction. Extending previous accounts of the design of CYSMN [Crabtree 2004] and preliminary observations of the game being played [Benford et al. 2003; Crabtree et al. 2004], we provide an integrated and extended account of the experience of CYSMN, focusing in particular on how both online and street players experienced the uncertainties inherent in GPS and WiFi, on the strategies that were implemented to deal with these, and draw out broader implications for the design of location-based experiences in general. However, before exploring these matters, we first provide a brief overview of CYSMN.

2. PLAYING THE GAME

An online player's experience begins at the CYSMN webpage where they can explore background information about the game, including instructions on how to play. They enter a name for themselves, followed by the name of someone that they haven't seen for a long time—a person that they are looking for. They then join the game queue (we restricted the number of simultaneous players to fifteen in order to limit network traffic flowing over both public Internet and local wireless network connections). When it is a player's turn to enter the game, they are dropped into a virtual model of the city at one of several predetermined start positions. This model shows the layout of the streets and outline models of

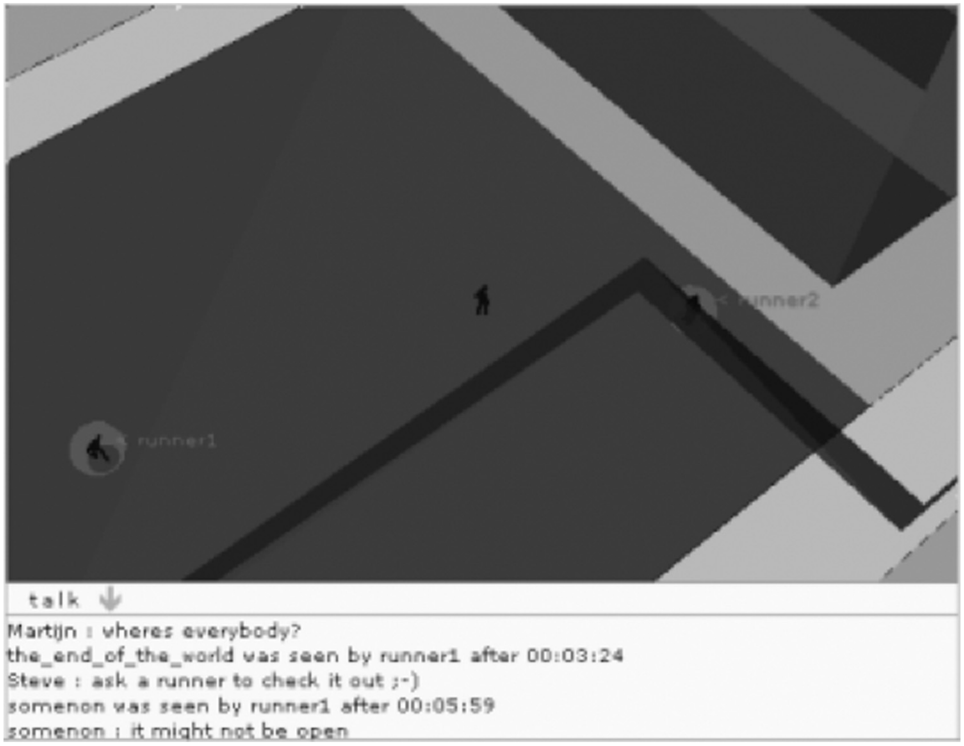

Fig. 1. Online player (center) tries to avoid two runners.

key buildings (in some cases including wire-frame representations of planned buildings that have yet to be constructed), but does not feature textures or details of dynamic objects such as cars and, of course, most of street population except the runners. Online players use the arrow keys on the computer keyboard to run around this model. They cannot enter solid buildings, cross virtual fences, or move out of the game zone, which is approximately 500 metres by 1000 metres. The players need to avoid the runners who chase them. Specifically, if a runner gets to within five virtual meters of an online player, the player is caught (although, we deliberately used the more open and ambiguous term 'seen') and is out of the game. Their score is the time elapsed since they joined the game.

Online players see themselves represented as running avatars, as are other players and the runners.[1] Players' avatars are labeled with their names and the runners are distinguished with a red sphere that makes them highly visible, even from a distance. Whenever an online player is running around, they see an aerial view of themselves from a tethered bird's-eye virtual camera. Figure 1 shows an example in which the player (centre of the image) is trying to avoid two approaching runners.

[1]In the first version of CYSMN in Sheffield the virtual city model was in fact a flat map with the players represented as simple icons. In subsequent versions it was a 3D model with players represented as running avatars.

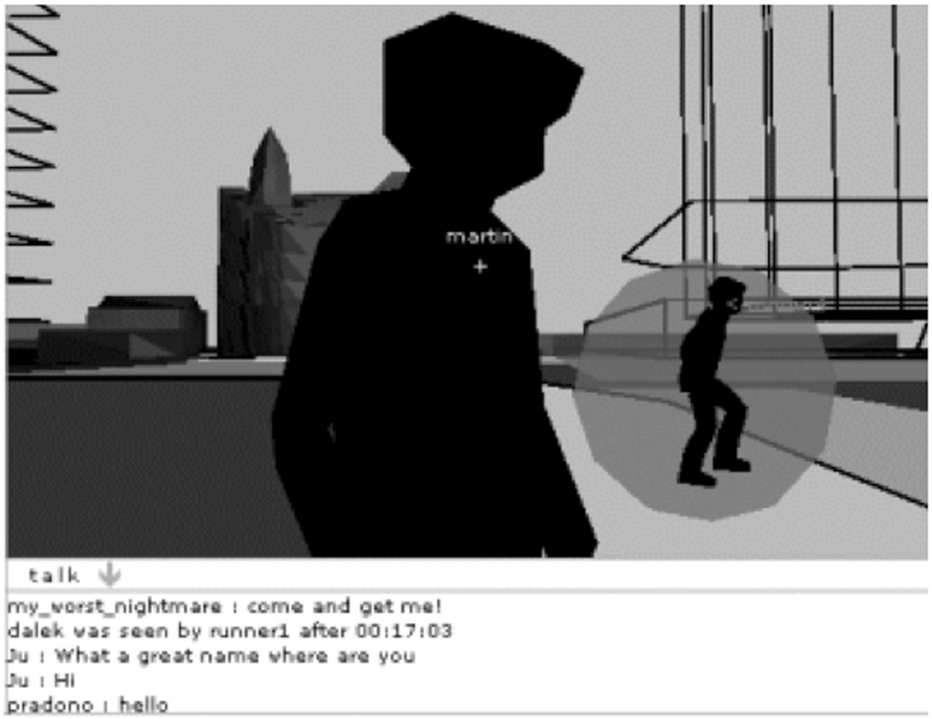

Fig. 2. Online player's view when standing still.

Whenever the player stands still (for example, when composing and sending a text message) the camera view drops down, zooms in and rotates around them until they begin running again. Figure 2 shows an example of this, where the player's avatar can be seen in the foreground with a runner approaching in the background. Online players can also select a zoomed out map view of the model, which shows the positions of more distant players and runners, as well as text labels giving the names of key locations, as shown in Figure 3.

Players can enter and view text messages that are seen by other online players and also by the runners, and they can hear a single audio stream that mixes together all of the runners' walkie-talkie communication. When an online player is caught, the virtual camera zooms down to their location and circles around them and a text message notifies them which runner has 'seen' them. Other online players also receive this message over the public text chat channel. Players can visit an archive website after the game, where they can review their own and other players' game statistics and download the sighting photographs that were taken by the runners. In particular, they can see the positions of all of the sightings of a given player overlaid on the 3D model of the city and can select any one of these to view the associated photograph. Most online players were physically remote from the host city, accessing the game over wide-area Internet connections (our most remote player was from a research-base in the Antarctic!). However, a few public Internet terminals available at each site where the game was actually deployed were used by local participants, which

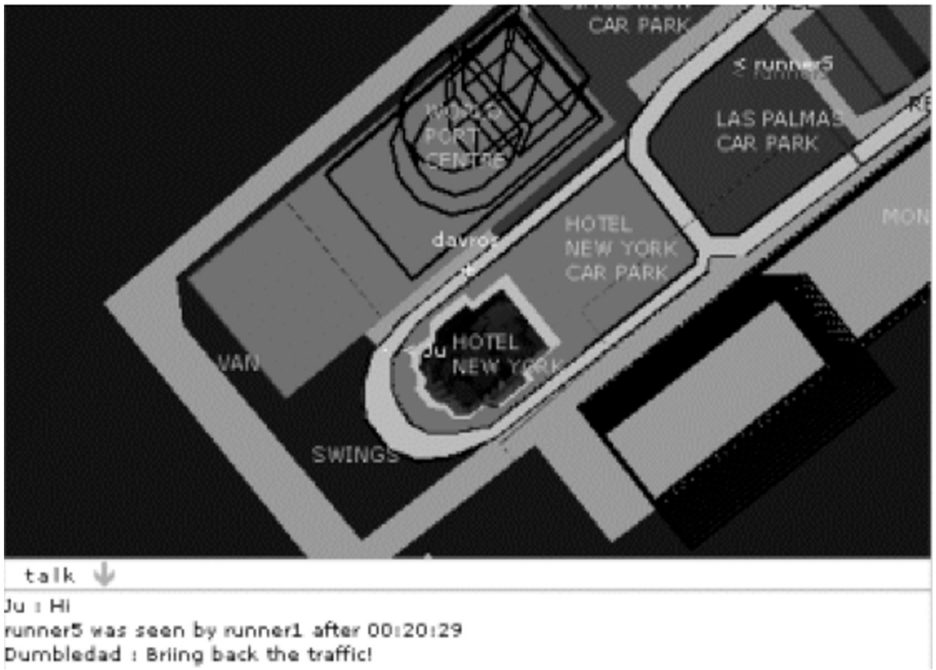

Fig. 3. Online player's interface—map view.

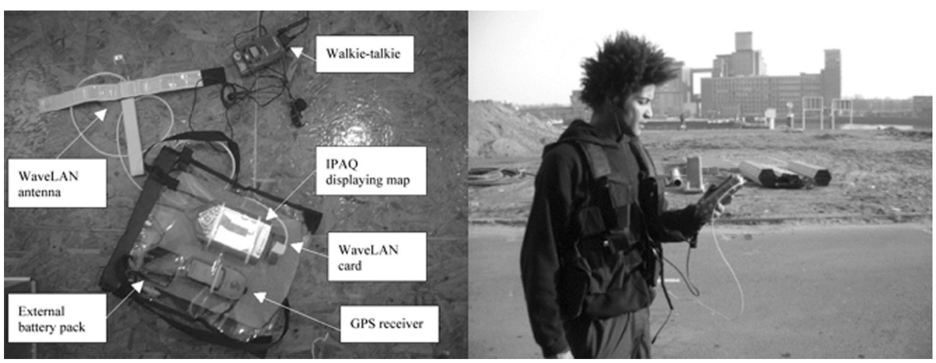

Fig. 4. A runner's equipment from first (left) and second (right) versions of CYSMN.

produced some interesting consequences. First, however, we must consider the runners means of playing the game.

The runners' interface was delivered on an HP Jornada handheld computer from a local server over a WiFi wireless local area network. A GPS receiver plugged into the serial port of the Jornada registered the runner's position as he or she moved through the city streets and this was sent back to the server over the wireless network. For the first version of the game in Sheffield in 2001, this equipment was simply mounted on a wooden board, enclosed in a waterproof plastic bag, and carried by the runners (Figure 4 left). For subsequent versions, it was built into a robust outer jacket (Figure 4 right).

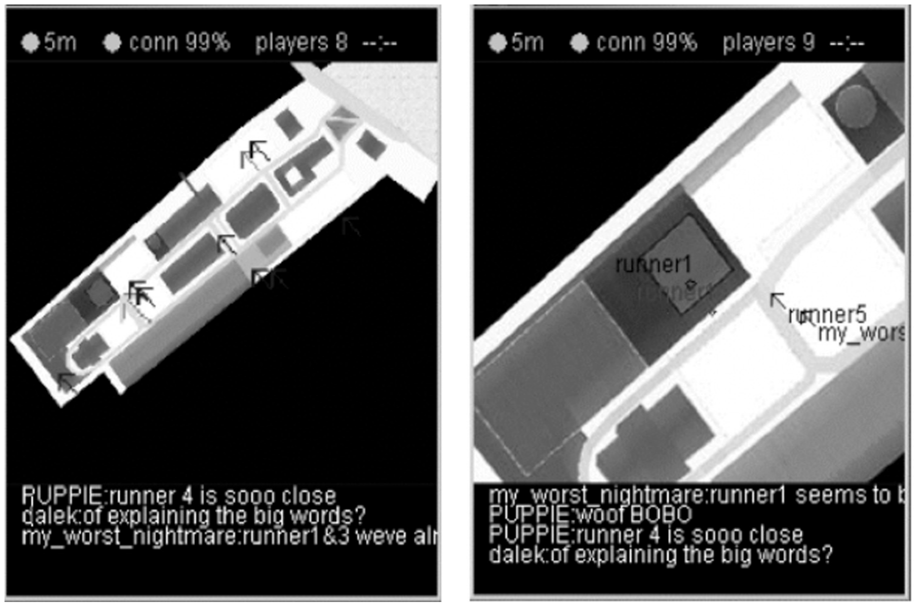

Fig. 5. The runner's interface—global view (left) and local view (right).

Given the small screen size of the Jornada, the runners' map allowed them to zoom between a global view of the gameplay zone and a close-up, local view that centerd on their current position—see Figure 5 left and right respectively, where blue arrows show runners, red ones online players, and the area at the bottom of the screen shows the most recent text messages from the players. The three pieces of information at the top of the interface in green show the current estimated GPS error as provided by the GPS receiver (left), the strength of the network connection (middle), and the number of online players currently in the game (right). The runners used walkie-talkies with earpieces and a head-mounted microphone to talk to one another. They could also talk to control room staff via the walkie-talkies on a separate and dedicated technical channel that was not streamed to the online players. The runners carried digital cameras so that they could take a picture of the physical location where each player was seen.

In addition to the 'front of house' aspects of CYSMN—the online players and runners views on the game—deploying CYSMN required the support of a technical crew who were housed in a makeshift control room located in the actual game zone. The control room was home to a staff of three who were responsible for running and managing the online server and supporting the runners. In addition to the dedicated walkie-talkie channel, they made use of a variety of monitoring and control interfaces to manage gameplay and tackle technical troubles as and when they occurred.

3. STUDYING CYSMN

We have followed an ethnographic approach to studying CYSMN as it has toured, focusing in particular on its first two performances in Sheffield in late

2001 and Rotterdam in early 2003. Ethnography is a natural observational method that seeks to provide rich descriptions of human activity and, in a design context, of technology use [Crabtree 2003]. It is one of the oldest methods in the social research armory and has been widely used in the design of interactive technologies, building on the recognition by designers that successful research and development increasingly relies upon an appreciation of the social circumstances in which systems are deployed and used. The method is particularly good at identifying and conveying to designers the 'workaday' character of interaction, thereby elaborating the demands that may be placed on new technologies in their use. In studying CYSMN we observed the activities of runners on the streets, online players, and technical crew in the control room, taking field notes and also capturing their activities on video for subsequent analysis. While it was relatively straightforward to gain access to the technical crew and the runners, studying the public players proved to be more of a problem as they could access the game from anywhere over the Internet and so were often physically inaccessible. Fortunately, most venues hosting CYSMN, including both Sheffield and Rotterdam, provided a suite of dedicated public terminals in an public area where we were able to observe and video some public players.

Another challenge with studying experiences such as CYSMN in which multiple players access a shared virtual environment over the Internet, is being able to reconcile the physical actions of the players with their corresponding activities in the virtual world and also the underlying behavior of the technology. Our approach here has been to instrument the system to generate time-stamped logs of all system events including:

- The movements of players' and runners' avatars and all catch events.
- Text messages that capture players communication with other players and the runners, providing insights into their experience.
- Audio recordings of the runners' combined walkie-talkie communication as streamed to the online players.
- Logs of the performance of the underlying infrastructure, especially of disconnections and packet loss for the WiFi network and availability and estimated accuracy for GPS.

These logs were analyzed manually, to examine players' online conversations, and also statistically, summarizing the performance of the technology. Such analyses can help explain players' actions in relation to other players and the operation of the underlying technologies, usefully supporting or contradicting direct observations or analysis of video recordings.

Our final source of data has been feedback from the participants themselves including emails and face-to-face discussions, and finally expert commentary in the form of critical review by members of the interactive arts community, essays written by arts students who had taken part in the game, and press reviews. This kind of feedback can give a broad sense of how a performance was experienced and can frame key issues for further investigation.

4. THE EXPERIENCE OF CYSMN

In general, CYSMN has been very well received by both players and critics. Discussions and feedback emails also highlighted several other key features of the experience that appear to have contributed to engagement and enjoyment.

The audio channel, the real-time walkie-talkie stream from the runners, was an essential part of the experience. Players reacted strongly to hearing their names mentioned, realizing that they had become the target of a chase and hearing the runners discuss their tactics. As one player put it in a subsequent email, “I only managed to get onto the map once for about 15 minutes. I can’t remember the name I used but it was pretty unnerving first hearing my name said.” Beyond this, the audio channel also provided a way for players to tune into the runners’ actual experience of the city streets, for example hearing them discuss crossing a road through busy traffic or sounding out of breath when talking about running up a hill. The experience was perhaps most successful when online players realized that their actions in the online world could affect events in the physical world, for example that the simple act of crossing a virtual line could cause someone to dodge real traffic. As our previous player also commented, “I figured out pretty quickly what was uphill and downhill. I also figured out which was the main road to cross.”

One of the most interesting features of the design in this regard is that the online players and runners inhabit separate ‘worlds’ or environments that are connected together virtually to create what we might call an *adjacent reality* rather than an augmented reality, which in its ideal tries to seamlessly connect one world to another. This structure combined with the audio stream encourages online players to imagine the runners’ experience through their verbal description of the physical world in relation to the virtual model. The second version of the experience in Rotterdam emphasizes this feature of the design by including several buildings in the virtual model that were currently only plans for the physical world, showing them as wire-frame representations.

However, there was one point at which the online and physical game spaces were visually connected, albeit by accident. In both the Sheffield and Rotterdam experiences the areas in which the public-play consoles were located contained small windows that looked out onto the physical game space. In both cases, some players reported enjoying deliberately positioning or moving their avatars in such a way as to cause runners to move into view. These rare moments of actually seeing a runner chasing their invisible avatar caused great excitement, suggesting that future versions of the experience might include this as a deliberate feature of the design, for example through the use of webcams pointing out into the physical game space.

This exchange of perspectives also highlights the importance of the sociality of gameplay in CYSMN. A minimal structure (a chase game) with only basic pre-programmed content (a static 3D model) appears to have established a framework that supported engagement and social interaction between the participants, both between players and runners and between the players themselves. The text logs show how the game provided a rich interactional context for players. Through texting, players collaborated to do such things as orient one another to the runners, help each other avoid runners, take evasive action, organize collaborative gameplay, and to both find and meet one another, as the following extracts from the log of text messages make visible.

Orienting other players to runners

#1. WILLEM: Where are the runners?
MARTIN: They're all around Las Palmas car park

#2. JOHN DOE: Runner 4 near cafe Rotterdam
TOBY: Heading up by Las Palmas
JOHN DOE: Runner 4 headed for Las Palmas

Helping other players to avoid runners

#3. DANI: Runner 3 at Las Palmas
PHIL: Runner 2 is nearby
CLAUDIA: Shit!!! Runner 3's on our ass
D.BOT: He's still on us—look out Catherine
DANI: Watch out Catherine

#4. SAAB: Mike meet me at cafe Rotterdam
MIKE: Sorry, stalking Anna
ANNA: That's okay Mike
SAAB: Stop stalking her then
MIKE: Anna has a nice butt
ANNA: How do you know?
MIKE: Big imagination
ANNA: Well you're right
SAAB: Mike watch the runner!

Taking evasive action

#5. DAVE: I'm in the south
ANDREW: Runner 4 is in the hotel car park
DAVE: Action
TOMMIE: Christine look right
ANDREW: Run for your lives!
JULES: Run baby run!
CHRISTINE: Thanks!
ANDREW: Runner 4 is west of the swings

#6. TAMA: Runner 1 at Las Palmas car park
ROBERT: North and east is clear
TAMA: Look out Ed! Runners 1 and 2 at Las Palmas

Organizing collaborative gameplay

#7. PAUL: No sign of the runners?
5000: I don't think so
NOBODY: They are in the car parks
5000: What are they doing there?
NOBODY: Chasing nobody
PAUL: It's probably a long way to get over here
PAUL: Lets run
5000: Where to?
PAUL: Lets meet the runners

#8. D.BOT: Runner 3 is still by Koolhaas I think
LANDO: Runner 4
SAN: Near Phil now
LANDO: He is heading to the car park
D.BOT: Bring Runner 3 over this way
CHRIS: I'm feeling suicidal

Finding other players

#9. AMMA: Running around to find Anna. Does anybody see her?
ROBERT: Anna is moving towards Hotel New York

#10. PENNY: Hello Steve we're looking for you
STEVE: I'm near Las Palmas—avoiding Runner 1

#11. VESPER: Jasper where are you?
JASPER: Behind Las Palmas

#12. MARCEL: Ali I'm somewhere around Las Palmas
ALI: How do I find Las Palmas?
MARCEL: Look at the map, right corner

Meeting other players

#13. VESPER: Let's all gather—makes things more exciting
ANNICK: Where?
VESPER: And when the runners come we scatter
PHIL: This could be interesting when they come running for us

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VESPER: Between Las Palmas and
Sumatra
ANNICK: OK
#14. JASPER: Hi Vesper
VESPER: Runner 2 is ahead
JASPER: Runner 2 on the move
VESPER: Better get moving
JASPER: I'm outta here
LANDO: Where are the runners?
VESPER: Wait for me!!
JASPER: All right
VESPER: Gather at Las Palmas everyone
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Although the engaging social character of the game is plain to see in the players' talk, staging CYSMN was not without its troubles, which provide important lessons for the design of similar experiences. Most notable among these are issues to do with dealing with the uncertainties inherent in the use of GPS and WiFi technologies and the complicated distributed orchestration work that this requires, two key issues that we focus on next and that form the basis for most of our subsequent discussion.

4.1 Uncertainty Arising from the Use of GPS and WiFi

One of the key issues to emerge from our studies has been the effect of uncertainty on the experience of CYSMN. In the following section, we focus on how position and connectivity were subject to uncertainty and provide an account of how players and runners experienced this. In turn, this leads us to propose several design strategies for coping with and even exploiting uncertainty. There were two primary technical sources of uncertainty in CYSMN—GPS and WiFi. The first uncertainty associated with GPS is its limited availability. It proved to be a constant battle for the runners to get a GPS fix at all. On entering the game it could take several minutes for their receivers to lock onto a sufficient number of GPS satellites and they would often lose sight of these as they entered GPS blackspots, such as the shadows of buildings. Without a GPS fix, the runners were unable to take part in the game. However, even when they could get a fix the issue of the positional uncertainty associated with GPS had to be reckoned with.

In Sheffield we used standard GPS with Garmin etrex receivers and the game zone spanned a mixture of open urban spaces with a few narrow and built-up side streets. Analysis of system logs showed that reported GPS error (as estimated by the GPS receivers themselves) ranged from 4m to 106m with a mean of 12.4m and a standard deviation of 5.8m. In Rotterdam, we upgraded to differential GPS and deployed Trimble Lassen LP receivers with Sarantel antennae. The game zone contained a similar mix of open spaces, several of which overlooked open water, having a good view of the sky to one side, and narrower built-up streets towards the centre of the game zone. Analysis of system logs showed that in this case, reported error ranged from 1m to 384m, but with a lower average error of 4.4m and a standard deviation of 4.9m. In order to improve accuracy the receivers were configured to ignore satellites that were low in the sky (below 15°), although this meant that it was then more difficult to get a GPS fix in the first place. In both environments there were also further blackspots where multi-path reflections led to particularly high errors and therefore large jumps in reported position. To compound matters, these uncertainties—availability and positional error—varied over time as well as over space as satellites moved across the sky (GPS uses low orbit arrays of satellites, which change their position relative to observers on the ground). Indeed, the game zone could move from providing generally good coverage to be almost unplayable and back again within a single game session (typically two hours).

WiFi networking was a further major source of uncertainty. Although we invested considerable effort in deploying WiFi in both game zones (we deployed an eight meter mast on a rooftop supplemented by two omni antennae in Sheffield; and a network of seven wireless access points, four of which were on buildings, one on a lamppost, one in a van, and one on a ship, in Rotterdam), coverage of each game zone was only partial. Consequently, runners would move in and out of connectivity, frequently leaving and rejoining the game. Analysis of system logs from Rotterdam revealed three broad categories of packet loss intervals: periods of short loss (less than 5 seconds) that account for 90.6% of loss intervals and were largely due to communication errors; 278 moderate periods of loss (between 5 seconds and 10 minutes) that were largely due to detours out of connectivity or interference; and finally two loss periods of about 15 minutes and one of about 40, resulting from major equipment failures. WiFi disconnections also meant that runners could not take part in the game and these would often occur in different places from GPS blackspots. Another kind of uncertainty associated with WiFi was delay, arising from a combination of network delays across the WiFi network, processing delays in the game server and also delays across the Internet to online players. Although variable, there was a typical delay of six seconds or more between one participant acting and another participant seeing that action. It should also be noted that the runners' speech was transmitted over a separate walkie-talkie channel which on the whole, provided broader coverage across the game zone than the WiFi network, although was sometimes subject to interference from other walkie-talkie and radio users.

A final source of uncertainty was occasional technical failures such as cables working loose and connectors being damaged (our runners were often running quickly and consequently their equipment suffered a battering) as well as 'soft' failures such as batteries running out of charge. These problems would add to GPS and connection problems. It can therefore be seen that the ability to effectively take part in CYSMN was subject to a wide range of contingencies producing uncertainties and that these were endemic to the experience, not just occasional problems. The next key question, then, is how did these uncertainties affect the experience?

4.2 The Online Players' Experience of Uncertainty

For much of the time online players appear to have been largely unaware of these uncertainties, in as much as the game continued in spite of them without obvious reference to them in text messages or indeed in subsequent feedback. However, this was not always the case and analysis of the text logs shows some occasions when their effects became apparent to players in different ways. WiFi disconnection or lack of a GPS fix meant that runners failed to appear in the game at all and there were many occasions where online players' text messages asked whether any runners were present and if so, where they were. However, a visible lack of runners was generally not attributed to technical problems. Indeed, given that no single player could see the whole of the game space, it was a natural part of the game to try to find out where runners were by asking other players if they were not directly in sight. Put another way, not giving online players a global view may have helped hide this particular uncertainty effect from them.

Another factor in hiding disconnection was the walkie-talkie channel, which was a separate channel from the WiFi data channel and so enabled the runners to continue streaming their talk to the online players even when not connected to the rest of the game. In fact, the runners deliberately adopted the tactic of talking more when disconnected, offering richer descriptions of their local environment in order to maintain the illusion that they were still actively participating in the game.

Given the degree of positional inaccuracy associated with the GPS, there was relatively little comment in text messages that runners were in the wrong place (players generally did not identify a mismatch between the positions reported by GPS and the runners' actual positions). One obvious reason for this is that with the small exception of a few players being able to look out of a physical window onto the game zone as described previously, the online players were not able to the see the runners' actual physical positions. Instead, their awareness of the runners' actual experience was through the audio channel, which gave a much 'fuzzier' sense of their location. Again, the design of the game—the adjacent rather than augmented reality structure and the streamed audio channel—may have served to hide some of the worst effects of uncertainty. This implies that the idea of using webcams to provide views into the physical game space as suggested previously should be treated with some caution.

There was a further way in which we deliberately extended the game server to hide positional uncertainty. We were aware that one noticeable effect of GPS positioning error might be to place runners' avatars in impossible locations such as inside buildings or in areas of water. We therefore added additional code to the game server to correct these kinds of positions, changing the displayed position to be the nearest possible correct position (e.g., a GPS position placing a player inside a building would be corrected to place their avatar at the nearest point on the street to this position). This would avoid obviously incorrect positions, although at the risk of making the avatars jump around on occasions (for example, a small movement in GPS might cause an avatar to suddenly flip between two different points on opposite sides of a building). The lack of comments on erroneous positions in online players' text messages suggest that this technique may have served its purpose.

However, there were clearly some occasions when online players did notice the effects of GPS and WiFi uncertainties. They sometimes noticed that runners' avatars would suddenly appear and disappear and would jump around (reflecting uncertainty in connectivity and GPS respectively), especially when they were caught as a result, as the following text log extracts show:

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#15. CHRISTINE: Did they get Tony?
JU: I don’t know I can’t see the runners
KALLE: Hmm the runners seems to jump around a bit
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#16. DIRK: Hey lucky
LUCKY: Hi Dirk
DIRK: Been here long?
LUCKY: What are we supposed to do?
ROBERT: The runners don’t have Internet. They only have GPS—and probably
some Nikes
LUCKY: They seem to appear quite randomly
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#17. ROBERT: Anyone seen where the runners are?
IAN: In the car park—near cafe Rotterdam
THE MIGHTY IDDO: Apparently it doesn’t matter—they boot you from miles
away
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#18. CHRIS: Runner behind us!
ANDREW: Runner 2 just appeared out of nowhere!
JASPER: I noticed—shit!!
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One player summed the experience up in a subsequent email, saying “A couple of times I was caught and I just hadn’t seen anything, which is a shame because the adrenalin rush when you see a runner approach and you try to escape is part of the draw in the game.” However, rather than seeing these noticeable effects of uncertainty as problems, other online players appeared to weave accounts of them into the structure of the game, attributing them to characteristics of the runners, including special powers:

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#19. MARCEL: Attention. Runner 1 is cheating by using his invisible coat
HBAB: What’s an invisible coat?
MARCEL: Never mind what the coat is—he can pop out of nowhere
```

```
#20. STEVE: Runner 4 keeps seeing me, but I don’t always see them
TOBY: Runner 1 you’re moving very fast
TRACY: Sure you’re not roller-skating?
ADAM: Ah! Where did Runner 2 come from?
```

Runners would sometimes mention the causes of uncertainty, especially GPS, over the public audio channel and some players picked up on this and used it to account for sudden captures and to make sense of the runners’ situation, as the following text extracts shows:

```
#21. A SPEEDING FERRARI: Don’t think Sheila is running right now
HARRIE: Where is she?
A SPEEDING FERRARI: Resting from the long chase after me
HARRIE: Is she lost?
HARRIE: Talk louder!
A SPEEDING FERRARI: WHY???
HARRIE: Talk!
RUNNER 4 HAS SEEN A SPEEDING FERRARI
HARRIE: What WOW?!
[Shortly afterwards] A SPEEDING FERRARI: Too bad the GPS is so unreliable—
I was supposedly seen with no runner in sight
```

```
#22. HOTEL NEW YORK: It looks like runners without a red circle don't have
GPS updates
PUPPIE: Yes hotel
HOTEL NEW YORK: I still see runner 4 in Las Palmas car park but he's not
moving
```

On other occasions, players thought that the runners could deliberately exploit the characteristics of GPS to their own ends:

```
#23. A LITTLE GREEN ALIEN: Sometimes I get seen while the runner is still
miles away—do others have this?
```

```
#24. MARJOLEIN: Anyone seen the runners?
MELISSA: I think they can turn off their signal
HANNE: I only see two runners—are the rest taking a coffee?
BLASTER: Runner 1 is just a lazy joke
HANNE: If they can turn off their signal that's pretty scary and not really
fair
MELISSA: Tell me about it
```

Alternatively, and interestingly, online players also recognized the tactical advantages of uncertainties for themselves:

```
#25. AMANDA: Hehe—first time I seen you in a while Dumbledad
EVIL ROB: Why are you all hiding here?
DUMBLEDAD: Yeah—fun place to meet
RUNNER 0: Are there any good places to get rid of a runner?
JASPER: It's nice over here
DUMBLEDAD: My tactic—don't tell anyone—is to not get bored of standing
still
AMANDA: If they catch a whole gang of us it will look like a massacre
DUMBLEDAD: It will
TIJN: Let's form a clan
PEYTHOR: A pixelated clan—a happy clan
DUMBLDAD: Not only have wee a scary looking dark building to hide behind but
its also crap GPS—pray hard to the anti-satellite god
```

To summarize, it seems that for much of the time, the worst effects of uncertainty were hidden from the online players by the structure of the game (at least to the point where they were not worthy of explicit comment). However, there were also many occasions when these effects did become apparent and when they did, they appear to have been experienced in a variety of ways. Sometimes they were highly noticeable problems, sometimes inexplicable, and sometimes even offered a tactical advantage to the players.

4.3 Runners' (and Crews') Experience of Uncertainty

In contrast to the online players, the runners and crew were very much aware of the uncertainties inherent in CYSMN. It was obvious to them when they weren't connected to the game, couldn't get a GPS fix, or when their position as shown on their mobile interface was different from their actual physical position. Indeed, runners had to wage a constant battle with these uncertainties in order to stage an experience for the online players. *Managing interruptions* caused by technological troubles was an essential feature of gameplay for the runners

Fig. 6. Seeing a disconnection: losing players.

[Crabtree et al. 2004] and the following sequences of interaction elaborate the work that was typically involved resolving them.

Sequence #1

Runner 2 on walkie-talkie. Runner 2. I've just lost all players; I've lost all players!
Runner 2: Looking at Jornada. I've got disconnection here.
The runner can do no other than abandon the chase, and he informs his colleagues and players alike that he has a specific problem and just where that problem is located.
Runner 2 on walkie-talkie: Runner 2. Heading seawards on Otto. I am currently disconnected.
He turns around and starts walking back down the street to the last known point at which he had connectivity. He arrives at the carpark where he last checked the Jornada.
Runner 2 on walkie-talkie: Runner 2. I've connectivity again. I'm in Vern.

Sequences of runners' work, gathered through video recording, show not only *what* sort of technical troubles impact upon interaction—in this case a disconnection from the wireless network—and *how* such interruptions impact upon interaction—causing runners to abandon the chase—but also, and importantly, they instruct us as to the competences involved in managing interruptions. We can see, for example, how in experiencing a disconnection, the runner makes the kind of interruption he is experiencing public knowledge. An interruption is *announced* to the other runners over the walkie-talkie, making others *aware* of the nature of the interruption and the location at which it occurs.

The runner repairs the interruption by retracing his steps and moving to a location where he last had connectivity. This strategy trades on and exploits both *working knowledge* of the technology—of knowing that disconnections are transient technical phenomena that may be resolved by moving to a better location—and *local knowledge* of the environment in which the technology is

Fig. 7. A visible incongruence between virtual and real.

situated—of knowing where in the environment is a 'better location' to move to. Furthermore, the sequence instructs us how such forms of knowledge are developed: through hands-on experience of using the technology *in situ* and through making others aware of and sharing knowledge of the interruptions encountered *as they occur*. Working knowledge of the technology and local knowledge of the environment combine through sharing to form a *common stock of knowledge* [Schutz and Luckmann 1974], which the runners exploit to manage and repair interruptions to interaction. This common stock of knowledge is developed and established over the duration of gameplay (i.e., over six days in this particular case).

Sequence #2
Runner 2 on walkie-talkie: Runner 2. I'm in pursuit of Dave.
He runs along a side-street, consulting the Jornada as he goes, turning left at the end of the street and going down Wilamena before slowing to a walk.
Runner 2 on walkie-talkie: Runner 2. I'm heading seawards on Wilamena, waiting for a server update.
He continues walking down the street, looking at the Jornada and his place on the street, seeing the incongruity between his virtual and real positions.
Runner 2 on walkie-talkie: My GPS is currently 35 metres. My server position is about 50 metres out.
Runner on walkie-talkie: This is Runner 2. Can Runner 1 and Runner 4 hear me, or Runner 3 please? Come in.
Runner 2 switches to the technical channel.
Runner 2 on walkie-talkie: This is runner 2 on 4 Zero. I can't get any response from anyone else on 238 (gameplay channel). Can you please confirm that the other runners are on 238?
Runner 2 on walkie-talkie: And who else is on 4 Zero (technical channel) please?
Runner 2: Runners 1 and 3 are having technical trouble. 4's in.
Runner 2 notices Runner 3 on the other side of the street and goes over to him.
Runner 3: Are you on 238?
Runner 2: I'm on 238, yeah.
Runner 3: OK.
Runner 2: I just switched back.
Runner 2: Looking at Runner 3's Jornada, whose case is open. What's the

```
problem?
Runner 3: Just not moving.
Runner 2: Yeah, I'm having the same. Looks like we have a bit of a server
screw up.
Runner 3: All right.
Runner 2 starts walking away from Runner 3.
Runner 2 on walkie-talkie: This is runner 2. I've had no GPS update in 2 or
3 minutes.
Runner walks towards the seafront, where he knows there is usually good GPS
coverage when it's available.
```

This sequence instructs us that working with constant interruption not only consists of developing a common stock of knowledge but that exploiting that stock of knowledge is intertwined with *diagnostic work*. While the nature of an interruption might be readily apparent—that the runner is 'stuck' as can be seen in the visible incongruity between the runner's virtual and the real positions—the source and/or the extent of such interruptions is not always clear. Runners do not know whether being stuck is a result of server problems, poor satellite availability or some other technical matter such as the disconnection of their GPS armband antenna or receiver from the rest of their equipment. Similarly, a runner does not know if it is an interruption only they themselves are experiencing or that others are experiencing too. And knowing such things is important because it informs the runner's decision-making—it helps them establish a sense of what it might be appropriate to do next in order to manage the interruption that is currently to-hand: should the runner exploit the common stock of knowledge and move to a better location for an update or is something more serious in progress that requires a full restart?

So runners need to diagnose interruptions in order to handle them. Like the production of the common stock of knowledge, diagnosis is a collaborative achievement and the sequence instructs us as to some of the ways in which that achievement is collaborative. On experiencing an interruption that is not quickly repaired runners consult one another via the walkie-talkies to establish which *channel* they are on (gameplay or technical) and to determine the gameplay *status* of others (whether others are playing the game or experiencing some interruption). The absence of a response from other runners in this case suggests that the interruption may be *widespread* and so the runner next consults control room staff via the walkie-talkie to establish whether or not that is the case.

Runners may also collaborate with one another directly (face-to-face) as they meet through happenstance on the streets. Although serendipitous in nature, this form of collaboration is nonetheless important. It allows runners not only to see for themselves the interruptions others are experiencing but also, as with indirect collaboration (via the walkie-talkie) with control room staff, to establish the *generality* of the interruptions. And therein lies the nub of the matter: diagnostic work is concerned to establish the generality of interruptions, which in turn informs their decision-making. Diagnostic work enables a runner to determine whether or not the interruption he is encountering is his alone, and related to his *personal kit*, or being experienced by others as well and related to the *game's technical infrastructure*. This, in turn, suggests the next move in

Fig. 8. Diagnostic work: moving from place-to-place.

managing the interruption: moving off to a better location and waiting for a GPS update as more satellites become available, for example, or restarting the Jornada, or even restarting the game if need be.

Our third sequence elaborates some more important features of the runners' diagnostic work.

Sequence #3

```
Runner 1 is walking around the Los Palmas carpark looking at her Jornada.
She crosses the road on Wilamena, going towards the seafront. She walks
across Simulation Carpark and then stops suddenly, holding the Jornada up in
front of her.
Runner 1 on walkie-talkie: Runner 1. I've got locations on players but I
seem to be stuck in New York.
Runner 1 turns around and starts to walk back towards Los Palmas carpark.
She stops at the roadside, looking closely at the Jornada. She turns around
again and walks back towards the seafront.
Runner 1 then heads back towards the road. She turns left and walks up
Wilamena, crosses the road, turns down the first alley she comes to on her
right and then turns right again at the end of that, heading towards Los
Palmas. Halfway down the street she comes across John, one of the control
room staff who also monitors the status of work on the streets as and when
technical troubles arise.
Runner 1: John, my position's gone really bizarre as in its not saying where
I am. And I know that it takes a while but I seem to be getting stuck in
really bizarre places. Like, I am not in Simulation carpark at the moment.
John: Looking at Jornada. No. The best thing to do is to stand out in the
middle of the carpark and just do a reset.
They both go to Los Palmas carpark and John resets the Jornada.
Runner 1: Brilliant, are we in the right place?
John: We've not got GPS yet. But, I think there's only about 3 satellites or
something.
Runner 1: I think runner 4's just dropped out of GPS.
They look up from the Jornada and see Runner 4 across the road, standing
beneath a waveLAN base station (where there should be good connectivity).
John: Looking across road. Runner 4 seems to be waiting.
```

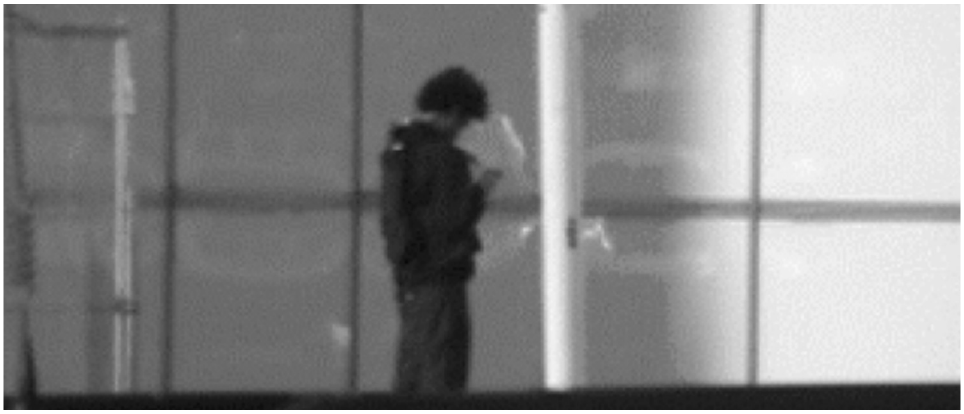

Fig. 9. Seeing that others are interrupted too.

```
Runner 1: Looking at Jornada. Yeah he is. He's just disappeared off here.
Runner 1 on walkie-talkie: Runner 1. Runner 4 can you hear me?
John: Are any runners running?
Runner 1: No.
John: Everybody's down?
Runner 1: I think so.
Runner 1 on walkie-talkie: Runner 2 what is your current situation?
Runner 1: He's got GPS.
Runner 1: Hup, I've got GPS.
```

This sequence extends our understanding of diagnostic work. It first draws our attention to a strategy for recognizing the *seriousness* of an interruption: moving from place-to-place. The strategy establishes that the interruption is more than a matter of a slow update in that it provides for its repair and, in failing to effect a repair, brings to light a technical gremlin that results in the runner 'getting stuck in really bizarre places.' The situation is repaired through serendipitous collaboration with a member of the control room staff, who resets the Jornada to eliminate one possible source of trouble. The sequence also makes it visible that runners consult one another when encountering serious interruptions, not only collaborating indirectly via the walkie-talkies, but also through *surreptitious monitoring* [Heath and Luff 1991] of the streets to see what others are doing and to establish whether or not the interruptions to-hand are local (of this kit) or general (of the technological infrastructure). The interruption in this case transpires to be general, which affects all the runners.

It is worth noting that the characteristics of the technology, once learned, could also be used to the advantage of the runners. Like some online players as noted previously, runners also tactically exploited their knowledge of GPS uncertainty. This became apparent after the initial Sheffield experience, as shown by the following conversation between a runner and a crewmember that took place back in the control room after a game:

Sequence #4

```
Crew: So your tactics: slow down, reel them in, and get them?
Runner: If they're in a place that I know it's really hard to catch them, I
```

```
walk around a little bit and wait till they're heading somewhere where I can
catch them.
Crew: Ambush!
Runner: Yeah, ambush.
Crew: What defines a good place to catch them?
Runner: A big open space, with good GPS coverage, where you can get quick
update because then every move you make is updated when you're heading
towards them; because one of the problems is if you're running towards
them and you're in a place where it slowly updates, you jump past them, and
that's really frustrating. So you've got to worry about the GPS as much as
catching them.
```

In summary, runners have to deal with several routine sources of uncertainty when playing the game, two of which are becoming disconnected from the game as a result of moving into a WiFi blackspot and losing GPS because of nearby buildings obscuring satellites. The uncertainties that arise from these technological problems are routine in the sense that they occur frequently and are, as such and to a certain extent, predictable. In many cases they will resolve themselves, as the speed of the chase carries them through problematic locations, sometimes without them even noticing. In other cases, such as in sequence 1, game play is interrupted and a more deliberate resolution is required.

While these two problems account for many of the runners' interruptions, there are several other problems that arise from time to time, and which also present themselves in the first instance as a breakdown in the runner's intended engagement with the online players. As we have seen, the runners' immediate diagnostic concern is to differentiate between problems that are specific to them as an individual—involving their personal equipment, or specific location—and problems of a more general nature that are out of their control, such as a failure of the network infrastructure or the game server. Nonroutine problems that appear to be specific to them as a runner require that they address other known issues of common knowledge such as mechanical or software failures, as is seen in the standard contingency of resetting the Jornada in sequence 3.

The runners employ a variety of competences and draw on different sources of information to deal with the causes of uncertainty and to manage and repair interruptions. They use the technical status information that is available to them on their Jornada. They then combine this with a common stock of knowledge that consists of working knowledge of the technology—of the ways in which GPS inaccuracies are manifest in interaction and local knowledge of the environment—of knowing where inaccuracies are manifest and positions where they might be resolved. This stock of knowledge is cumulative, assembled collaboratively over the course of interaction, and dynamic, changing according to the environmental factors framing the present moment of interaction. This shared information provides for the moment-by-moment orchestration of the experience and involves discussions with technical crew in the control room, on the streets, and of direct and indirect encounters with other runners during which they compare the state of their systems and update the common stock of knowledge.

5. IMPLICATIONS FOR DESIGN

Our observations show that uncertainty, of both location and connectivity, was a significant and ongoing issue in the playing of CYSMN. They also reveal that uncertainty is a complex issue that can affect participants' experiences in different ways depending upon their role (whether they are a public online player or a professional actor who is running on the streets in order to deliver the experience to online players), the extent of their technical knowledge, and the information that is currently available to them. We believe that such uncertainties are a fundamental characteristic of location-based experiences, and that they will remain so for the foreseeable future, which leads us to consider how designers can systematically reason about and design around them.

5.1 Designing for Four States of Being

We begin by focusing on the mobile player. Our first suggestion is quite simply to avoid the trap of assuming that the technology will work reliably; in other words, to avoid designing solely for the situation in which the mobile player is connected and their location is tracked. In contrast to designing conventional applications in which input technologies such as mice work reliably and disconnections tend to be exceptional events, we encourage the designers of location-based experiences to explicitly consider the following 'four states of being' of a mobile player:

- They can be **connected and tracked**, being within both network and positioning system coverage.
- They can be **tracked but not connected**. For example, their local device is receiving GPS updates and can update its local display accordingly, but is unable to communicate these updates to other players.
- They can be **connected but not tracked**, in which case their device can exchange updates and communication with other players, but cannot inform them of its position or update the local display according to the participant's movements.
- They can be **neither connected nor tracked**, in which case their device does not know its location and cannot communicate with other players.

Designers need to consider how a player might end up in each of these states and what should be done about it. Specifically, they need to provide some level of continued and meaningful experience for each state, rather than simply assuming that an error has occurred and potentially leaving the player alone and lost in the middle of a city. A wide range of options is available to the designer at this point, for example continuing with a downgraded experience, switching over to low-tech fallback solutions, or informing the player how to move to a more useful state (e.g., indicating where to go in the city in order to reestablish connectivity or tracking). In the following discussion, we group the available options into five general strategies for dealing with uncertainty: remove it, hide it, manage it, reveal it, and exploit it.

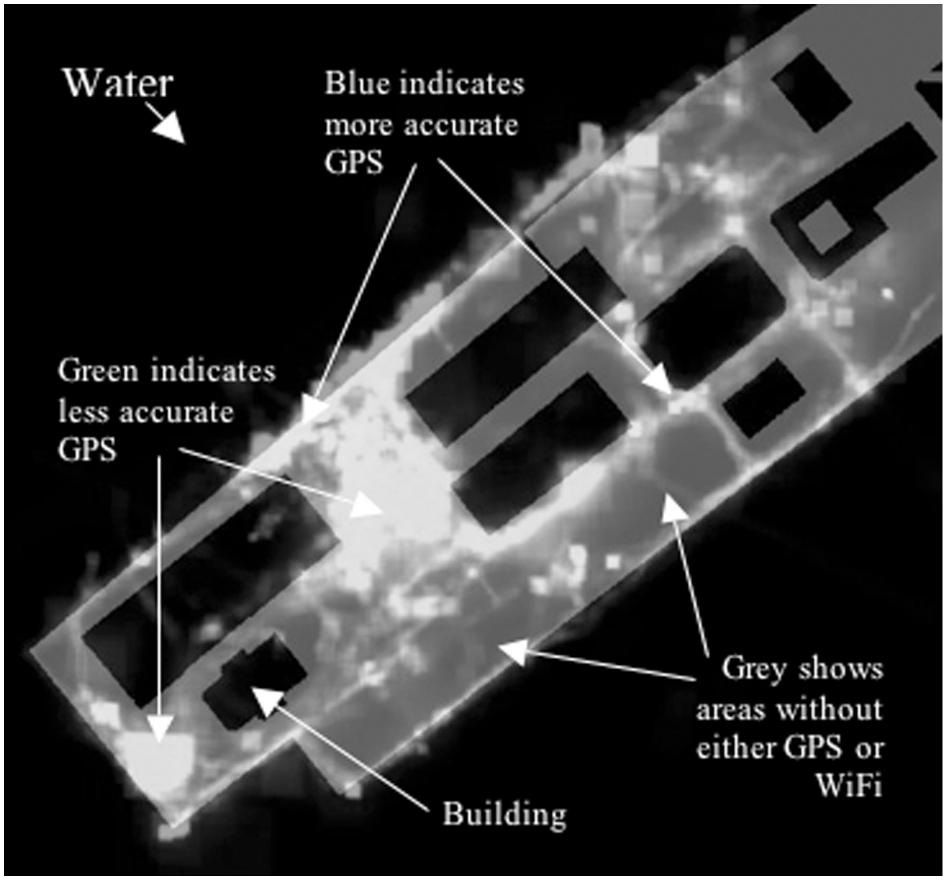

Fig. 10. Visualization of GPS history from CYSMN.

5.2 Remove Uncertainty

One way of dealing with uncertainty is to try to remove it. In the long term, this might involve developing new forms of location-sensing and wireless networking. In the medium term it might involve improving the performance of existing technologies, for example adding additional antennae and access points to improve coverage, or using multiple technologies in concert, switching between different networking technologies with different coverage characteristics, or following the approach of sensor fusion [Wu et al. 2002], in which multiple sensing technologies are used together, using techniques such as particle filters [Hightower and Borriello 2004].

In the short term, an alternative and pragmatic strategy is to design the experience to closely fit the capabilities of the technology, for example carefully choosing the game zone to avoid canyons and blackspots. GPS and network traffic logs from Rotterdam showed that some locations, especially the narrow built-up streets in the center of the gameplay zone, were consistently poor with regard to positional accuracy and/or connectivity (see Figure 10). Removing these areas from the game would have also removed some of the uncertainty. However, our analysis of CYSMN also showed a variation in GPS uncertainty over time, suggesting that designers also need to consider their choice of playing times as well as playing zones.

An example of this strategy in use is the location-based game Savannah in which groups of six children role-play being lions on a virtual savannah that appears to be overlaid on an empty school playing field—a location that was deliberately chosen to minimize problems with both GPS and WiFi [Benford et al. 2004a]. However, in many cases this strategy will not be available to designers as locations and playing times may be determined as much by access, safety, and sponsors' needs, as they are by suitability to the underlying technology. These are also significant factors for nongaming applications, as one cannot reasonably ask the providers of location-based services to move their premises just to fit the technology.

5.3 Hide Uncertainty

Our second strategy is to design the experience to hide the worst effects of uncertainty. We have already seen several ways in which this strategy was utilized in CYSMN:

- Our position correction scheme for the runners' avatars filtered out situations where inaccurate GPS measurements would place them in obviously impossible locations, such as inside buildings or in the water.
- We deliberately used the term 'seen' rather than 'caught' to introduce a degree of fuzziness as to how close a runner had to get to a player.
- Online players could not see an overview of the entire game space, making it difficult for an individual player to spot that there were no runners in the game.
- The use of streamed audio as the main channel through which online players directly experienced events proved to be a rich source of context and was highly atmospheric, yet was not overly precise in terms of allowing a direct comparison between the positions of the runners shown in the virtual world and their actual positions on the city streets.
- The adjacent reality structure of the experience, in which the online and physical worlds were maintained as separate but interconnected environments rather than being directly overlaid on one another, also prevented users from directly comparing actual and reported positions.

By employing tactics such as these, and in particular by avoiding setting unrealistic expectations through metaphors that cannot be delivered by the technology (trying to create the illusion that a virtual world is seamlessly superimposed on the physical world when positioning technologies cannot really deliver this, for example), we suggest that designers may be able to hide some of the worst effects of uncertainty.

5.4 Manage Uncertainty

Our third strategy is to manage the uncertainty. One option here is to fall back to a downgraded but continuing experience. Uncertainty of connectivity might be dealt with by implementing baseline experiences for both street and online players that can continue when the connection between them is lost. For example, some core content that remains usable in a stand-alone mode can be replicated on a street player's mobile device. Unavailability of positioning can be dealt with by temporarily falling back to manual solutions such as 'self reported positioning' [Benford et al. 2004b], in which players declare their positions both explicitly (e.g., by marking their location on a digital map) or implicitly (e.g., implying their possible location through which area of the map they are currently looking at). Self reported positioning could also be used to correct inaccuracies in automated positioning as part of an ongoing dialogue between the player and the positioning system.

A second aspect of managing uncertainty is orchestration, where performers and technical crew shape a player's experience in real-time from behind the scenes. Orchestration work has been a focus of previous studies of interactive performances. Studies of *Desert Rain* [Koleva et al. 2001], a previous collaboration between the Mixed Reality Laboratory and Blast Theory, revealed the subtle ways in which performers monitored participants' actions and intervened in them, often without being noticed. Similarly, studies of *Avatar Farm* [Drozd et al. 2001], an improvised drama involving members of the public and actors in a collaborative virtual environment, highlighted the problems faced by invisible stagehands as they tried to manipulate virtual objects in order to improvise magical effects.

CYSMN offered a further opportunity to study orchestration work, but this time in a more 'decentralized' situation [Juhlin and Weilenmann 2001], where orchestration work was a prominent feature involved in 'making the technology work' on the streets [Crabtree et al. 2004]. Our study of CYSMN showed that orchestration was essential to the experience and was a distributed collaborative process in which control room staff and runners monitored the state of the technology and intervened, both remotely using walkie-talkies, or in more extreme cases through face-to-face interventions on the streets, drawing on a common stock of knowledge as to the current state of the underlying technologies in relation to the game space. Designers of other location-based experiences need to consider to what extent orchestration is appropriate and viable and what combination of social processes and technologies is required to facilitate it.

5.5 Reveal Uncertainty

Our fourth strategy is to deliberately reveal uncertainty to participants. Our experience of CYSMN suggests that runners were better able to work with the uncertainties of GPS and wireless networking once they had built up a working knowledge of their presence and characteristics, something that we enabled by providing some information about estimated GPS error and connectivity on their mobile interface. The approach of revealing uncertainty was more evident in the control room, where a variety of interfaces provided detailed information about the behaviour of GPS and wireless networking in relation to each runner so that the technical crew could troubleshoot the system and advise the runners how to proceed over the walkie-talkie system during orchestration work. Although this strategy of revealing the uncertainties in the infrastructure to some participants does seem to have helped them work with the technology, we feel that we could have gone further. Runners' main concerns when faced with problems were whether they should move to a new location or whether their equipment was somehow malfunctioning (in which case they should call out a member of the technical crew to assist). In addition to showing current GPS error and signal strength, we should also have given the runners a sense of how uncertainty varied across the game zone and over time.

This approach of revealing uncertainty is familiar from everyday mobile phones where information about signal strength is routinely made available to users to help them deal with uncertainty of connectivity. Previous research in mobile and ubiquitous computing has also explored revealing uncertainty as part of a more general dialogue between users and sensing systems. One of the earliest location-based applications, the Lancaster GUIDE, made information about current connectivity and location accuracy available to users [Cheverst et al. 2000]. Interfaces in the Aware Home project from the Georgia Institute of Technology were intended to help its occupants reflect on the operation of sensing technologies, for example the 'Sesame Street Kitchen People Counter,' a portable display that showed the system's current estimate of the number of people in a room; and 'Cartoon Parts,' a display that revealed how much information it could sense (using video recognition) about its viewers [Kidd et al. 1999]. Newberger and Dey [2003] have extended the Context Toolkit to enable users to monitor and control the behaviors of context aware applications, and Mankoff et al. [2000] have developed tools to help mediate ambiguous input through dialogue with users (see also, Dey et al. [2002]).

Indeed, several researchers have made more general arguments in favor of greater dialogue between users and ubiquitous technologies rather than designing for invisibility. Bellotti et al. [2002] have argued that in order to be understood and controlled, context aware computing systems will need to reveal their properties to users, leading to their five questions for the designers of sensing systems. In a similar vein, Mynatt and Nguyen [2001] observed that:

> "More subtle dangers of invisible computing are interfaces that do not give people the needed tools of awareness and control to comprehend and shape the behavior of the system. Too often, ubicomp designers favor the benefits of implicit input without considering the dangers of invisibility."

Experimental work has demonstrated some tangible benefits of revealing uncertainty, for example, leading to improved human performance in memory related tasks with ubiquitous technologies [Antifakos et al. 2004]. There is also experimental evidence from other areas of HCI that revealing uncertainty can improve user performance, for example, revealing network delays in collaborative applications can improve performance [Gutwin et al. 2004].

5.6 Exploit Uncertainty

Our observations showed that both online players and runners were sometimes able to exploit GPS uncertainty to their tactical advantage. Perhaps designers can deliberately use uncertainty as a positive feature of an experience, requiring players to seek out areas of good connectivity and sensing, or conversely, enabling them to hide away 'in the shadows' of poor coverage. This approach has recently been captured in the idea of 'seamful design,' a proposal that designers should recognize the natural seams in technologies—the places where they may imperfectly connect to one another or to the physical environment—and should design applications that deliberately exploit them [Chalmers and Galani 2004]. Examples of seamful location-based games include *Noderunner* (www.noderunner.com) in which the aim is to deliberately seek out and connect to as many islands of WiFi connectivity as possible within a city; and *Bill* (ibid.), in which players have to leave network connectivity in order to collect gold coins and then return back to connectivity in order to deposit them and score points, but where other players can steal them on the way via peer-to-peer connections, requiring players to reason about the boundaries of connectivity.

A second aspect of exploiting uncertainty is to make use of the ambiguity that is inherent within it. It has recently been proposed that the deliberate use of ambiguity may be useful in HCI for creating engaging and provocative interfaces, challenging the conventional view that ambiguous interfaces should be avoided [Gaver et al. 2003]. Accordingly, designers might employ a range of tactics for exploiting ambiguity in order to provoke interpretation. For example, by providing fuzzy representations of GPS positions in the online virtual world (e.g., as 'probability clouds,' fleeting shadows, or perhaps even by simply replacing an avatar with an enigmatic question mark), could designers turn the conventional avatar that shows position into a more open question, requiring participants to figure out where the tracked person is by reflecting more deeply on the information that is available to them? This is analogous to the technique of *sfumato* in painting, a style of brushwork that deliberately reduces the definition of information in order to create ambiguity, for example as used by Leonardo Da Vinci to create the famous smile of the Mona Lisa.

6. REDESIGNING CYSMN TO BETTER DEAL WITH UNCERTAINTY

Clearly, designers can respond to uncertainty in a variety of quite different ways. Furthermore, the five strategies that we have outlined above are not mutually exclusive, but may instead be used together within the same experience to meet the needs of different participants. The general approach in CYSMN is to hide uncertainty from online players while simultaneously revealing it to runners and also to technical crew who are responsible for managing it through a process of orchestration. Indeed, this is a key aspect of our approach; we suggest that it is not *always* desirable to enter a dialogue with users about uncertainty, or even to try to remove it, but rather, designers should seek to balance the different strategies available to them, especially where one category of users is providing an experience for another, such as is the case with a live performance or possibly a game. Nevertheless, although CYSMN could clearly be made to work, there was room for improvement. The common stock of knowledge exploited by runners and technical crew was really only available through the runners' talk and, occasionally, in the talk between runners and control staff. As the common stock of knowledge is predicated on technical events, however, the possibility exists of making it more directly available as a shared resource by visualizing the state of the underlying infrastructure.

6.1 Developing Color Maps of 'Good' and 'Bad' Areas

Uncertainty might be revealed to the runners and technical crew by providing them with explicit information about GPS and WiFi coverage. This might be achieved by providing maps that show 'good' and 'bad' areas of coverage. This augments the common stock of knowledge with timely infrastructure-derived data so that runners can identify problematic and trouble-free areas and online players can make sense of the uncertain and often erratic movements of runners. The same technique might also be applied to the management interfaces in the control room to promote awareness across the division of labor. This can build on an existing mechanism in CYSMN where artists configure the game by coloring maps. At present, they color in possible start positions for online players (the game engine chooses one of these each time an online player is introduced into the game), and also areas such as buildings and water where runners are not allowed to appear, triggering the position correction algorithm described previously. Our proposed extension involves *dynamic* color maps that are created and also updated from a mixture of logged, live, and predicted information. We have developed two prototype visualizations as first steps towards this.

Our first design prototype visualizes the history of GPS availability and error as reported by GPS receivers in order to build up a picture of good and bad locations. Figure 10 shows a visualization of GPS error over a two-hour game session that has been manually overlaid on a simple map of the game zone. The solid black inner areas are buildings and the surrounding black area is water. Colored points are locations where a GPS reading was successfully transmitted to the game server over WiFi and logged. In other words, each point of color represents a position at which there was both GPS and WiFi coverage at some point during the session. The color then indicates how good the GPS coverage was. Green blooms signify readings with larger errors (5 meters or above) and blue blooms signify readings with smaller errors (approaching 1 meter). Larger errors also produce larger blooms due to the uncertainty in the reported position. Grey areas with no color, show locations where no readings were obtained, either because there was no GPS or WiFi coverage, because they were inaccessible to runners (some were fenced off), or because runners never ventured there. This visualization serves a dual purpose of revealing areas of expected WiFi connectivity and also giving historical clues to the generally quality of GPS accuracy that might be anticipated in different places.

6.2 Visualizing Predicted Future Coverage

We know that GPS exhibits considerable variation over time as the GPS satellites move across the sky. Our second design prototype predicts the likely

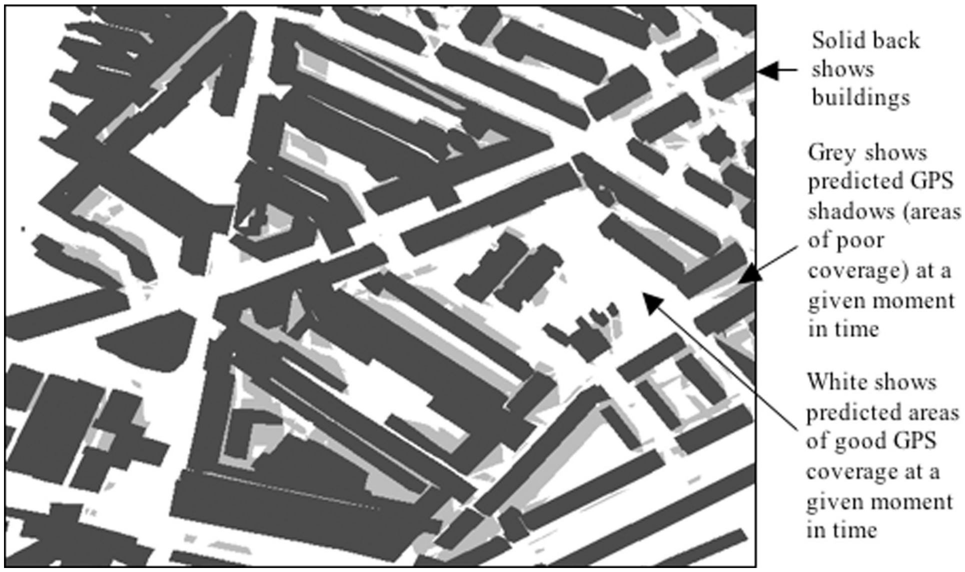

Fig. 11. Visualization of predicted GPS availability.

availability of GPS at different locations on the streets at *specific times,* rather than the broader historical trends revealed by the first visualization. This visualization takes the 3D model of the game zone and information about the positions of GPS satellites at a given moment in time and for each location on the ground, calculates how many satellites are in its direct line of sight. The output is a map of expected 'good' and 'bad' areas of GPS availability, as shown in Figure 11.

In this example, which shows an area of a city, buildings are shaded black, areas of likely good GPS (with predicted line of sight to three or more satellites) are shaded white, and areas of poor GPS (line of sight to less than three satellites) are shaded grey. Access to this information, could give the runners much more timely and fine-grained hints to resolving GPS problems than might easily be acquired through first-hand experience, and provide online players with a resource with which to make sense of the uncertainties encountered in their interactions with runners, and furnish a resource that may be exploited to tactical advantage. Ongoing work is exploring how these visualizations can be combined and integrated into CYSMN to provide effective support for orchestration work on the streets and to enable online players to interpret the ambiguities encountered in gameplay.

The purpose of these visualizations is to help deal with uncertainty by revealing the gaps and breaks—or the 'seams'—in gameplay and to make them available as resources that the runners and players might exploit to make sense of the technical circumstances effecting interaction. This might be achieved in several ways. Visualizations of the likely state of the infrastructure (potentially based on a combination of these approaches) might be overlaid on the runners' maps on their PDAs (see Figure 5 for current examples of maps), enabling them to see areas of good and bad coverage, develop a sense of stable and unstable areas over the evolving life-span of the game, identify areas where coverage and connectivity is consistently good or bad, and decide for themselves where to go to in order to restore WiFi and GPS when disconnected. Similar visualizations might be displayed in the control room so that technical crew can advise runners before or during a session and can more easily resolve technical difficulties. Given the shifting nature of coverage across a game zone, these visualizations would ideally be updated on an ongoing basis from coverage and accuracy data gathered from runners' PDAs during play.

Visualizations of the state of the communications and positioning infrastructure might also aid experience designers. Recent research has proposed new tools to enable the designers of mobile experiences to configure content by drawing trigger zones over maps of a physical game zone, including the Mediascapes tool in which location-based triggers are specified as vector shapes [Hull et al. 2004] and the ColourMaps tool, which enables artists to directly paint trigger zones over a map [Flintham 2005]. We propose that in order to specify appropriate triggers, designers need to be aware of the characteristics of the technical infrastructure across the game zone as well as its physical layout. Choosing where to place triggers and what size and shape they should be requires an understanding of both physical access to a location and also whether communications and sensing are available. We therefore suggest that design tools should overlay visualizations such as those in Figures 10 and 11 over physical maps as an aid to designing the content of location-based experiences.

More generally, seams such as limited connectivity and positional accuracy are a natural product of technology *use*, especially where the use of mobile and wireless applications is concerned. While technology providers suggest that there are no limits to connectivity and mobility, service coverage is anything but seamless in the real world. Rather, connectivity tends to patchy and better in some places than others. While seams may be thought of as technical by-products that will be eradicated in time through further development and the delivery of improved services, a different view might be adopted that sees seams as a valuable resource for interaction [Chalmers et al. 2004]. Our studies of gameplay show that runners and players are already aware of seams in various ways; that they are available in their activities and often appealed to make sense of gameplay, though this 'appeal' often requires a considerable amount of work. What the above visualizations seek to do is make the seams more visible so that users might recognize the seams that affect their work much more easily and exploit them as a resource for getting the work done.

Moving beyond the confines of CYSMN, we suggest that the designers of mobile and wireless technologies seek to exploit the seams that are manifest through usage to enable users to exploit and incorporate them into their activities. Rather than treating seams as manifestations of bugs and glitches and striving for seamless connections, designers might recognize that connectivity is not constant or perfect. The designers of mobile phones already recognize this, providing representations of signal strength, for example. The design community might transcend this limited example (and by an order of magnitude) by suspending a concern with the repair of bugs and glitches to consider instead, the ways in which the seams between a range of technologies such as GPS, GSM, 3G, WLAN, WiFI, and Bluetooth (etc.) might be *intentionally* revealed and transformed into a functional resource through 'seamful design' [Chalmers and Galani 2004].

7. CONCLUSION

Can You See Me Now? (CYSMN) is a touring artistic performance in the form of a game in which online players, members of the public log on over the Internet, are chased through a virtual model of a city by runners (professional performers equipped with PDAs with GPS receivers and wireless networking) who had to run through the actual city streets in order to catch them. Our observations of the public deployment of CYSMN have shed light on the ways in which different participants in an interactive game that mixes online and street players works with a combination of sensing and networking technologies to create and sustain an ongoing experience.

It is clear from our observations that fundamental characteristics of sensing and wireless communications technologies, namely frequent disconnection and uncertainty of positioning, strongly influence participants' experiences. It is also clear that different participants respond to these in different ways. Consequently, we have encouraged designers to deal with uncertainty as an ongoing aspect of location-based experiences. Unlike 'wireful' technologies, where disconnections tend to be an exceptional event that can often be treated as a bug or error, disconnections are an ongoing fact of life for wireless technologies. We have proposed that designers should explicitly address four possible 'states of being' of a mobile participant: connected and tracked, connected but not tracked, tracked but not connected, and neither connected nor tracked. We have then outlined five different strategies for coping with these states, which might be mixed and matched within a single experience to meet the needs of different participants:

- **Remove uncertainty**—remove some uncertainty by developing improved technologies, investing more resources in deploying current technologies or in carefully choosing the location and time of the experience to fit the technologies.
- **Hide uncertainty**—consider structures that hide uncertainty from key participants, for example the adjacent reality structure of CYSMN where online players have only limited and fuzzy connections to the physical world (e.g., through audio) and where the game software fixed positions to appear to be more credible.
- **Manage uncertainty**—adopt various fall-back strategies such as providing some minimum level of experience that will continue to work even when disconnected or using manual self-reported positioning techniques when automated positioning is unavailable. Managing uncertainty can also involve behind the scenes orchestration.
- **Reveal uncertainty**—reveal the presence, magnitude and scope of uncertainty to some participants. Examples include providing visualisations of

areas of good and bad connectivity and position through dynamically created color maps.

- **Exploit uncertainty**—some participants may be able to exploit technical uncertainties as part of the experience, for example, leading to the idea of seamful design, experiences that deliberately make use of limited connectivity (requiring participants to locate areas of connection or alternatively to hide in areas of disconnection) or inaccurate positioning. Artists might even deliberately exploit technical uncertainties to create ambiguities that provoke engagement and reflection.

Our ongoing work is concerned to further develop these ideas, both by extending *Can You See Me Now?* as it continues to tour (e.g., deploying enhanced orchestration tools) and also in the design of further experiences such as *Uncle Roy All Around You,* a further performance in which both street and online players work together to track down a mysterious figure as they journey across a city [Benford et al. 2004b]. In conclusion, our studies of *Can You See Me Now?* have demonstrated how staging and studying public performances can be a powerful approach to understanding the potential of new and emerging technologies 'in the wild.' Accordingly, we plan to continue our collaborations with artists to design, deploy, and study public performances as a foundational approach to conducting HCI research.

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The following web resources provide additional material related to this article. The Blast Theory website with information about the group and ongoing projects (www.blasttheory.co.uk); *Can You See Me Now?* archive website from the first performance in Sheffield (www.canyouseemenow.co.uk); *Can You See Me Now?* archive website from the second performance in Rotterdam (www.canyouseemenow.v2.nl); archive of research videos, including documentation of *Can You See Me Now?* and *Uncle Roy All Around You* (www.crg.cs.nott.ac.uk/∼sdb/videos); and the Equator IRC website (www.equator.ac.uk).

REFERENCES

ANTIFAKOS, S., SCHWANINGER, A., AND SCHIELE, B. 2004. Evaluating the effects of displaying uncertainty in context-aware applications. In *Proceedings of the 6th International Conference on Ubiquitous Computing*, Nottingham, UK, September, Springer-Verlag, 54–69.

BELLOTTI, V., BACK, M., EDWARDS, W., GRINTER, R., LOPES, C., AND HENDERSON, A. 2002. Making sense of sensing systems: Five questions for designers and researchers. In *Proceedings of the 2002 CHI Conference on Human Factors in Computing Systems*, Minneapolis, Minnesota, April, ACM Press, 415–422.

BENFORD, S., ANASTASI, R., FLINTHAM, M., DROZD, A., CRABTREE, A., GREENHALGH, C., TANDAVANITJ, N., ADAMS, M., AND ROW-FARR, J. 2003. Coping with uncertainty in a location-based game. In *IEEE Pervasive Computing 2*, 3, 34–41.

BENFORD, S., ROWLAND, D., FLINTHAM, M., HULL, R., REID, J., MORRISON, J., FACER, K., AND CLAYTON, B. 2004a. Designing a location-based game simulating lion behaviour. Paper presented at the *Proceedings of the ACM SIGCHI Conference on Advanced Computer Entertainment 2004*, Singapore, June, ACM Press. http://www.nestafuturelab.org/research/draft/05draft01.htm.

BENFORD, S., SEAGAR, W., FLINTHAM, M., ANASTASI, R., ROWLAND, D., HUMBLE, J., STANTON, D., BOWERS, J., TANDAVANITJ, N., ADAMS, M., ROW-FARR, J. OLDROYD, A., AND SUTTON, J. 2004b. The error of our ways: The experience of self-reported position in a location-based game. In *Proceedings of the 6th International Conference on Ubiquitous Computing*, Nottingham, UK, September, Springer-Verlag, 70–87.

BJÖRK, S., FALK, J., HANSSON, R., AND LJUNGSTRAND, P. 2001. Pirates!—using the physical world as a game board. Paper presented at the *Proceedings of IFIP TC.13 Conference on Human-Computer Interaction*, Tokyo, Japan, July, International Federation for Information Processing, http://play.tii.se/publications/2001/piratesshort.pdf

CHALMERS, M. AND GALANI, A. 2004. Seamful interweaving: Heterogeneity in the theory and design of interactive systems. In *Proceedings of the 2004 ACM Symposium on Designing Interactive Systems*, August, Cambridge, Massachusetts, ACM Press, 243–252.

CHALMERS, M., DIEBERGER, A., HÖÖK, K., AND RUDSTRÖM, Å. 2004. Social navigation and seamful design. In *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, vol. *11*, 3, 171–181.

CHEVERST, K., DAVIES, N., MITCHELL, K., FRIDAY, A., AND EFSTRATIOU, C. 2000. Developing a context-aware electronic tourist guide: Some issues and experiences. In *Proceedings of the 2000 CHI Conference on Human Factors in Computing Systems*, The Hague, Netherlands, April, ACM Press, 17–24.

CRABTREE, A. 2003. *Designing Collaborative Systems: A Practical Guide to Ethnography*. Springer-Verlag, London.

CRABTREE, A. 2004. Design in the absence of practice: Breaching experiments. In *Proceedings of the 2004 ACM Symposium on Designing Interactive Systems*, Cambridge, Massachusetts, August, ACM Press, 59–68.

CRABTREE, A., BENFORD, S., RODDEN, T., GREENHALGH, C., FLINTHAM, M., ANASTASI, R., DROZD, A., ADAMS, M, ROW-FARR, J., TANDAVANITJ, N., AND STEED, A. 2004. Orchestrating a mixed reality game 'on the ground'. In *Proceedings of the 2004 CHI Conference on Human Factors in Computing Systems*, Vienna, Austria, April, ACM Press, 391–398.

DEY, A. K., MANKOFF, J., ABOWD, G., AND CARTER, S. 2002. Distributed mediation of ambiguous context in aware environments. In *Proceedings of the 15th Annual Symposium on User Interface Software and Technology*, Paris, France, October, ACM Press, 121–130.

DROZD, A., BOWERS, J., BENFORD, S., GREENHALGH, C. AND FRASER, M. 2001. Collaboratively improvising magic: An approach to managing participation in an online drama. In *Proceedings of the 7th European Conference on Computer Supported Cooperative Work*, Bonn, Germany, September, Kluwer Academic Publishers, 159–178.

FLINTHAM, M. 2005. Painting the town red: Configuring location-based experiences by colouring maps. In *Proceedings of Advanced Computer Entertainment (ACE 2005)*, Madrid, Spain, ACM.

GAVER, W., BEAVER, J., AND BENFORD, S. 2003. Ambiguity as a resource for design. In *Proceedings of the 2003 CHI Conference on Human Factors in Computing Systems*, Florida, USA, April, ACM Press, 233–240.

GUTWIN, C., BENFORD, S., DYCK, J., FRASER, M., VAGHI, I., AND GREENHALGH, C. 2004. Revealing delay in collaborative environments. In *Proceedings of the 2004 CHI Conference on Human Factors in Computing Systems*, Vienna, Austria, April, ACM Press, 503–510.

HEATH, C. AND LUFF, P. 1991. Collaborative activity and technology design: Task coordination in london underground control rooms. In *Proceedings of the Second European Conference on Computer Supported Cooperative Work*, Amsterdam, The Netherlands, September, Kluwer Academic Publishers, 65–80.

HIGHTOWER J. AND BORRIELLO, G. 2004. Particle filters for locations estimation in ubiquitous computing: A Case Study. In *Proceedings of the 6th International Conference on Ubiquitous Computing*, Nottingham, UK, September, Springer-Verlag, 88–106.

HULL, R., CLAYTON, C., AND MELAMED, T. 2004. Rapid authoring of mediascapes. *Proceedings of Ubicomp 2004*. Springer, 125–142.

JUHLIN, O. AND WEILENMANN, A. 2001. Decentralizing the control room: Mobile work and institutional order. In *Proceedings of the 7th European Conference on Computer Supported Cooperative Work*, Bonn, Germany, September 2001, Kluwer Academic Publishers, 379–398.

KIDD, C., ORR, R., ABOWD, G., ATKESON, C., ESSA, I., MACINTYRE, B., MYNATT, E., STARNER, T. E., AND NEWSTETTER, W. 1999. The aware home: A living laboratory for ubiquitous computing research. In *Proceedings of the 2nd International Workshop on Cooperative Buildings*, Pittsburgh, USA, October, Springer-Verlag, 191–198.

KOLEVA, B., TAYLOR, I., BENFORD, S., FRASER, M., GREENHALGH, C., SCHNÄDELBACH, H., VOM LEHN, D., HEATH, C., ROW-FARR, J., AND ADAMS, M. 2001. Orchestrating a mixed reality performance. In *Proceedings of the 2001 CHI Conference on Human Factors in Computing Systems*, Seattle, Washington, ACM Press, 38–45.

MANKOFF, J., HUDSON, S., AND ABOWD, G. 2000. Interaction techniques for ambiguity resolution in recognition-based interfaces. In *Proceedings of the 13th Annual ACM Symposium on User Interface and Software Technology*, San Diego, California, November, ACM Press, 11–20.

MYNATT, E. AND NGUYEN, D. 2001. Making ubiquitous computing visible. In *Proceedings of the 2001 CHI Conference on Human Factors in Computing Systems* (Workshop 10. Building the Ubiquitous Computing User Experience), Seattle, Washington, April 2001, ACM. Press. http://www2.parc.com/csl/projects/ubicomp-workshop/positionpapers/mynatt.pdf

NEWBERGER, A. AND DEY, A. 2003. System support For context monitoring and control. Position paper presented at *Proceedings of the 5th International Conference on Ubiquitous Computing* (Workshop 7. At the Crossroads: The Interaction of HCI and Systems Issues), Seattle, Washington, October, Springer-Verlag, http://ubihcisys.stanford.edu/online-proceedings/Ubi03w7-Newberger-final.pdf

PIEKARSKI, W. AND THOMAS, B. 2002.‘ ‘ARQuake: The outdoors augmented reality system. *Comm. ACM 45*, 1, 36–38.

SATOH, K., OHSHIMA, T., TAMAMOTO, H., AND TAMUARA, H. 1998. Case studies of see-through augmentation in a mixed reality project. In *Proceedings of the 1st IEEE International Workshop on Augmented Reality*, San Francisco, November, IEEE Computer Society, 3–18.

SCHUTZ, A. AND LUCKMANN, T. 1974. *The Structures of the Lifeworld*, Heinemann, London.

STARNER, T., LEIBE, B., SINGLETARY, B., AND PAIR, J. 2000. MIND-WARPING: Towards creating a compelling collaborative augmented reality game. In *Proceedings of the 5th International Conference on Intelligent User Interfaces 2000*, New Orleans, January, ACM Press, 256–259.

WU, H., SIEGEL, M., AND ABLAY, S. 2002. Sensor fusion for context understanding. In *Proceedings of the 19th IEEE Instrument and Measurement Technology Conference*, Anchorage, Alaska, May, Institute of Electrical and Electronic Engineers, http://www.ri.cmu.edu/pubs/download

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