Orchestrating a Mixed Reality Game 'On the Ground'

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ABSTRACT
Successfully staging a mixed reality game in which online players are chased through a virtual city by runners located in the real world requires extensive orchestration work. An ethnographic study shows how this concerted achievement extends beyond the control room to the runners on the street. This, in turn, suggests the need to 'decentralize' orchestration and develop support for collaboration 'on the ground'. The study leads to design proposals for orchestration interfaces for mobile experiences that augment situational awareness and surreptitious monitoring among mobile participants and support troubleshooting in situations where participants are disconnected or are unable to access positioning systems such as GPS.

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Design, Human Factors

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Mobile & wireless games, ethnography, orchestration, GPS

INTRODUCTION
The control room has assumed a prominent position in the effort to understand the collaborative nature of human-computer interaction. In studies of the London Underground, the coordination of urban traffic flows, space shuttle missions, ambulance dispatches, air traffic control, the handling of emergency calls, and more recently, the orchestration of mixed reality performances [12], the control room has been of reoccurring interest and relevance due to its grossly collaborative character. Historically, the control room might be seen as a 'perspicuous setting' allowing researchers to investigate the nature of collaboration and explore the potential for systems design.

It has also been recognised, however, that control rooms are part of a wider social division of labour and that mobility across the division of labour is critical to collaboration [1, 13]. Attention has accordingly been extended to consider collaboration 'on the ground' [11]. This shift in focus recognizes that collaboration in control rooms is bound up with the collaborative work of others located elsewhere and that there is a need to develop a 'decentralized' perspective if collaboration across the division of labour is to be improved through technology development.

The shift towards decentralization recognizes that support for 'ground workers' needs to be predicated on their day-to-day concerns, rather than on the perceived concerns of ground workers as seen and understood from the centralized perspective of the control room. This, of course, is not a radical issue but a familiar concern to CHI practitioners that recognizes the 'invisibility' of collaboration to members (or users) differently located in the division of labour [4, 17]. Neither is it an argument to abandon the lessons learnt from the control room to date but, for sound reasons of research, to move beyond the well-studied confines of the control room and explore the potential challenges and benefits of supporting collaboration 'on the ground'.

This paper trades on, complements and further elaborates the shift towards decentralization. We present an ethnographic study of a mixed reality game in which online players interacted with players located on a city's streets [8]. Previous research in mixed reality performances has concentrated on the 'orchestrated' character of interaction with an emphasis on the work of control room staff [2, 7, 12]. Recognition of the problems of scale and mobility occasioned by large numbers of participants interacting via wireless networks has led researchers to consider ways in which orchestration may be decentralized, however. Our studies suggest that this research challenge may be usefully informed by close and careful inspection of collaboration 'on the ground'. Demonstrably, such a focus not only sensitises design to the concerns of ground workers but, in situated details of the methodical ways in which those concerns are practically managed [9], highlights ways in which decentralization might be facilitated through design.

STUDYING COLLABORATION 'ON THE GROUND'

When studying collaboration 'on the ground' ethnographically [6] we are concerned to explicate or make visible what Harold Garfinkel [9] calls 'the vulgar work of the streets'. 'Vulgar' is not to be understood in a pejorative sense, but etymologically as referring to things commonly or ordinarily done. What Garfinkel is interested in is the ordinary work of a setting, and more specifically, with the ordinary competences that people routinely and methodically exercise to concert or orchestrate their activities. Work is a matter of competence for Garfinkel and the methodical exercise of competence results in – indeed is identical with – distinct setting-specific practices. The practices we are interested in are those implicated in 'making the technology work' [5]. Again, there is nothing radical in this approach – following Suchman [16] it is foundational to our understanding of collaboration.

The Technology

In this case, the work in question is a mixed reality game called *Can You See Me Now?* (CYSMN) which involves participants in a game of chase in both real and virtual space. Up to 15 simultaneous online 'players' logged in on the Internet are chased through a virtual model of a circumscribed area of a city by 4 'runners', professional performers, who are located on the actual city streets and are equipped with handheld computers [8]. We briefly review the structure of the game and the technologies involved prior to examining the collaborative nature of human-computer interaction 'on the ground'.

From an online player's point of view, interaction is mediated via an abstract 3D graphical model of the streets. This model allows players to see the positions of other players and the runners (Figure 1) and to exchange text messages. The players move through this model with a fixed maximum virtual speed.

Figure 1. Players' perspective (runner highlighted)

From the runners' point of view interaction is also mediated via an abstract perspective, this time of a 2D map on a handheld computer (Figure 2). As they move through the real city streets, runners can see the positions of players (marked by coloured arrows) and other runners (marked by differently coloured arrows), can read players' text messages, and can communicate with one another using walkie-talkies with earpieces and head-mounted microphones. The runners' talk is streamed to control room staff and players, and runners can also communicate with control room staff and one another on a dedicated technical walkie-talkie channel that is not heard by the online players.

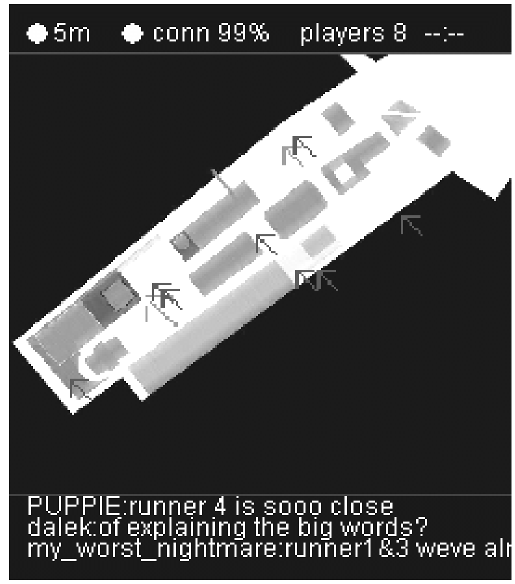

Figure 2. Runners' perspective

The runners' interface was delivered on an HP Jornada from a server located in a building on the city streets over a WiFi (802.11b) wireless local area network. A GPS receiver plugged into the serial port registered the runner's position as they moved through the streets and this was sent back to the server over the wireless network. Three pieces of information displayed at the top of the runner's interface showed the current estimated GPS error as provided by the GPS receiver (Figure 2, top left), the strength of the network connection (middle), and the number of online players currently in the game (right). When a runner gets to within five virtual meters of an online player, the player is 'seen' and is out of the game.

Human-Computer Interaction: Working with Constant Interruption

Previous accounts of CYSMN have focused on the overall design of the game and on the impact of GPS error on participant's experiences [8]. This study extends this work to consider ways in which the game was orchestrated in interaction, focusing particularly on the work of the runners 'on the ground' and their collaboration with players, control staff, and one another. The study was conducted when the game was staged on the streets of Rotterdam for 6 hours a day over 6 days in February 2003, during which time it received over one thousand online plays.

The study revealed that the most fundamental challenge for the runners was dealing with interruptions to the game. Working with 'constant interruption' [14] is an irremediable feature of using the technology for two main reasons. Firstly, 802.11b networking has limited coverage. Even though we deployed seven wireless access points throughout a game space that was roughly 400 meters by 800 meters, the narrow and built up nature of the city streets resulted in many network blackspots where runners could not connect to the game. Secondly, GPS is subject to the contingencies of satellite availability. If too few satellites are visible from a runner's current location (perhaps due to being in the shadow of a building or there being only a few satellites passing overhead at that moment) a runner will not be able to get a GPS 'fix' and will be unable to play the game. Managing interruptions is, therefore, an essential feature of gameplay for the runners insofar as they must be handled and repaired if interaction is to proceed. The following sequences of interaction elaborate the work typically involved in 'managing interruptions' on the ground.

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.

Figure 3. Seeing a disconnection: losing players

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 show not only *what* sort of technical interruptions 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 situated – of knowing where in the environment is a 'better location' to move to. Furthermore, the instance 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* [15], 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 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.

Figure 4. A visible incongruence between virtual and real

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 (which occasionally happened as they were running for hours at a time, placing the equipment under considerable stress). 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 – i.e. 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 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 needs 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.

Figure 5. Diagnostic work: moving from place-to-place

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).

Figure 6. Seeing that others are interrupted too

John: Looking across road. Runner 4 seems to be waiting.

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 here 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* [10] of the streets to see what others are doing and to establish whether or not the interruptions to-hand are local (i.e., of this kit) or general (of the technological infrastructure). The interruption in this case transpires to be general, which affects all the runners.

Summary

Close and careful inspection of collaborative work 'on the ground' has elaborated the 'vulgar' competences through the methodical exercise of which interaction is ordinarily orchestrated *by runners* on the streets. In particular, our runners have to deal with two 'routine' problems: becoming disconnected from the game as a result of moving into a WiFi blackspot and losing GPS because of nearby buildings obscuring satellites. In each case, they can work individually to resolve the problem by moving to an appropriately 'better' location. These are both routine in the sense that they occur frequently and – at least to some degree – predictable as the runners move around the game space, playing the game. In many cases they will resolve themselves, as the runners movement carries them across a problem area, sometimes without them even noticing. In other cases, such as sequence 1, game play is interrupted and a more deliberate resolution is required.

While these two problems account for many of the runner's interruptions there are several other problems which 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 which are specific to them as an individual – involving their personal equipment, or specific location – and problems of a more general nature which are out of their control – such as a failure of the network infrastructure or the game server. Non-routine problems which 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 PDA in sequence 3.

The runners employ a variety of competences and draw on different sources of information to deal with these issues and so manage and repair interruptions. They use the technical status information that is available to them on their PDA. 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 encounters with other runners during which they compare the state of their systems and update the common stock of knowledge.

DECENTRALIZING ORCHESTRATION

Our observations show that runners were able to routinely and collaboratively deal with interruptions and successfully orchestrate gameplay on the ground in spite of various technical difficulties. However, this is not to say that this is always easy, as the runners lacked a global perspective on the game and up-to-date information about the status of the technology and other runners.

Although runners were aware that a good response to an interruption was often to move to a new location, it wasn't always clear as to *just where* this should be. While the runners' common stock of knowledge provided a shared sense of 'good' and 'bad' areas of play, the runners nevertheless lacked detailed real-time knowledge of *just how* WiFi and GPS coverage was varying across the environment at any particular moment in time. At the time of the study, control room staff were aware of variations in satellite availability, having assembled prediction charts from the US Naval Air Warfare Centre Weapons Division website [18]. While the runners were briefed on availability and variation prior to each game, the specific implications of this information were only 'discovered' in the course of interaction and in terms of interruptions. Because runners did not have detailed and timely information about WiFi and GPS coverage to hand during the playing of the game, serious interruptions often occasioned collaboration with control room staff to determine satellite status and inform decision-making. Clearly the possibility exists to decentralize such information and give runners control of the resources *they need* to manage interruptions, make decisions, and orchestrate their actions.

In the course of managing interruptions it is also clear that runners were interested in knowing the status of their colleagues so that they could judge how widespread a problem might be. However, this information was only available to them if they were fortunate enough to encounter other runners on the street. It was generally difficult for runners to learn about the status of remote runners on demand, or even to know where to go in order to meet them, as knowledge of their locations would be lost during disconnection. Control room staff were also unaware of the location or status of disconnected runners other than through audio reports via the walkie-talkie channel, limiting their ability to guide them. Added to this was the occasional problem of having to change walkie-talkie channels due to interference from other sources, which sometimes made it difficult for runners to determine which new channel to use. Having said this, using walkie-talkies rather than WiFi for audio – and hence a completely independent wireless technology – provided two independent coordination channels, allowing a degree of continued coordination and experience even in the face of failures in one medium.

We therefore suggest a shift in focus, away from supporting orchestration behind-the-scenes or 'backstage' in the control room to 'frontstage' on the ground, by enhancing the information that is available to the runners and augmenting situational awareness. This is not intended to eliminate the need for the control room, the technical infrastructure still needs to be maintained and the occurrence of serious interruptions may well merit the deployment of technical 'SWAT' teams on the streets [4], but decentralizes orchestration and broadens support across the division of labour to enable ground workers to better orchestrate interaction for themselves. We propose several extensions to our system to address these limitations.

Colour-maps of 'Good' and 'Bad' Areas

Our first extension involves giving the runners access to additional explicit information about the expected spatial availability of GPS and WiFi by colouring the map on the runner's PDA interface to show 'good' and 'bad' areas of coverage. This allows the runners to supplement their personal experience and *augment the common stock of knowle*dge with timely infrastructure-derived data so that they know where to go in order to rejoin the game. (The same technique might also be applied to the management interfaces in the control room to promote further awareness). This builds on an existing mechanism in CYSMN where artists configure the game by colouring maps. At present, they colour 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 (if a GPS update places a runner inside one of these regions, the system moves their visible position to be the nearest location that is just outside of it). Our proposed extension involves *dynamic* colour maps that are created and also updated from a mixture of logged, live and predicted information. We have developed two prototype visualisations as first steps towards this.

Our first design prototype visualises 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 7 overleaf shows a visualisation 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 areas are buildings and the surrounding area is water. Colored points are locations where a GPS reading was successfully transmitted to the game server over Wifi and logged. Green blobs signify readings with larger errors (5 meters or above) and blue blobs signify readings with smaller errors (approaching 1 meter). Larger errors also produce larger blobs 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 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.

We know that GPS exhibits considerable variation over time as the GPS satellites move across the sky overhead. Our second design prototype predicts the likely availability of GPS at different locations on the streets at *specific times,* rather than the broader historical trends revealed by the first visualisation. This visualisation takes the 3D model of the game zone and information about the positions of GPS satellites at a given moment in time – for the runners that would normally be 'now' – (see [17]) 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 8 below. In this example, which is an area of central London, buildings are shaded black, areas of likely good GPS (with line or sight to three or more satellites) are shaded white and areas of likely poor GPS (line of sight to less than three satellites) are shaded grey. Access to such information, would give the runners much more timely and fine-grained hints to resolving GPS problems than might easily be acquired through first-hand experience. Ongoing work is exploring how these visualizations can be combined and integrated with the runner's handheld interface to provide effective orchestration support.

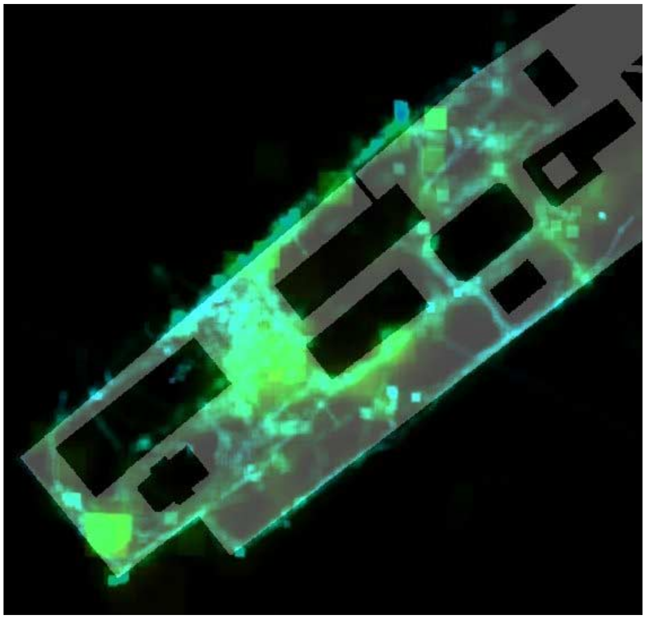

Figure 7. Visualization of GPS history from CYSMN

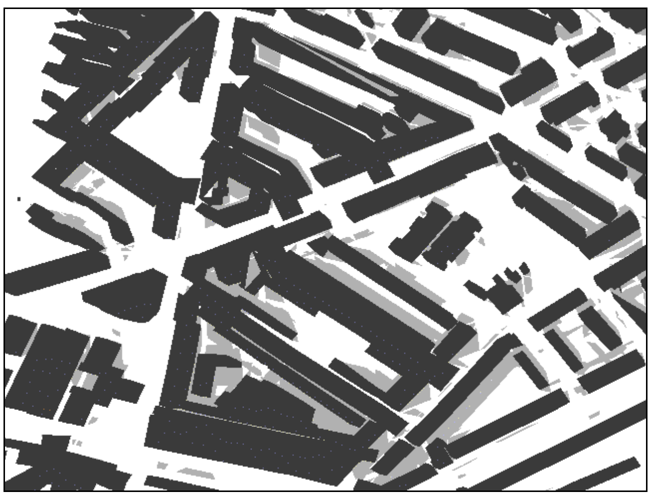

Figure 8. Visualisation of predicted GPS availability

Knowing the Status of Other Runners

Our second extension involves making runners more aware of the status of other runners, providing them with the information they need to surreptitiously monitor others remotely and determine the local or general scope of interruptions at-a-glance, thus aiding diagnostic work. GPS and connection status are generally available to the system and each runner already sees their own information on their local PDA. The extension is to make this information available to other runners when possible. However, capturing information about the current walkie-talkie channel requires an extension to the system, perhaps initially in terms of an interface in the control room or on each runner's PDA for manually updating this data.

However, more severe difficulties arise when there are GPS problems, in which case a runner's current location is unknown, or worse still a failure in the wireless network, in which case no status information can be sent to or from this runner (even if their GPS is working). Dealing with these situations leads us to consider various further design ideas.

The first of these is to provide information about the last known status during disconnection. For example, when a runner suffers disconnection, their PDA interface may continue to display the last known positions and statuses of other runners and similarly, the other runners may continue to see the last known status of this runner. However, it will be important to clearly distinguish between last-known state and live state, and also convey a sense of how stale this information is, for example, by displaying how much time has elapsed since the last update from a given runner or even having the information fade from view over time. One problem with the last known state is that it only shows the point at which things went wrong. In order to support backtracking into areas of good coverage, it will be useful to display a trail of states leading up to the point of failure.

Second, we can provide alternative technical modes of communication to supplement the centralised (Access Point-based) WiFi approach used in CYSMN. For example, we would normally expect GPRS (GSM) coverage to be more complete than WiFi in any given area, and to be less affected by nearby buildings (because of the different radio frequencies that it operates on). So the runner's device could be engineered to fall back to GPRS after it has been out of WiFi range for some critical period of time. The reduced bandwidth and higher usage cost of GPRS are likely to mean a reduced engagement while using GPRS, in the most extreme case, just a diagnostic or support channel to facilitate their re-discovery of a WiFi region and to allow them to discount other technical problems. A different option is to use WiFi in a peer-to-peer communication mode, so that runners could communicate with one another on a one-to-one, ad-hoc basis. This would make centralised coordination and management of the game difficult or impossible in the general case, so in this kind of scenario the use of peer-to-peer communication might be best limited to out-of-band awareness, coordination and trouble-shooting activities, with the game play as such still being handling by the assumed common WiFi infrastructure with its servers and control room.

Our third and final proposal deals with the situation where a runner loses GPS but remains connected to the game. In this case, we recommend falling back to alternative positioning systems. These might include approaches based on WiFi or GPRS/GSM signal strength, radio beacons, or even – perhaps the most robust – a manual positioning system where the runner explicitly shows their current position to others. For example, we might utilise the self-reported positioning technique that was developed to support a recent mixed reality game in which participants on the streets declared their position to the game server simply by dragging a 'me' icon across their PDA map using a stylus [19]. Even if not used directly as part of the game play (as this could be considered to be cheating), this kind of simple fallback mechanism enables runners to report their position to the control room and to other runners while trying to regain a GPS fix. It may also be used by other participants on the streets who are not directly involved in the game, such as mobile technical crew who become serendipitously involved in resolving technical problems.

CONCLUSION: MOVING OUT OF THE CONTROL ROOM

The control room has been central to the effort to understand the collaborative nature of human-computer interaction. It has also been recognised, however, that control rooms are part of a wider division of labour and that there is now a need to extend the design focus and consider collaboration 'on the ground', especially given the recent growth of interest in mobile, location-based and context aware applications. We have articulated this shift towards decentralization through ethnographic study of street players or 'runners' orchestration of a mixed reality game. Here, on the streets, human-computer interaction observably relies on the collaborative production of a common stock of knowledge and on monitoring other participants to diagnose interruptions.

Common interruptions occur for two main reasons: network blackspots and the contingencies of satellite availability. Essentially, the common stock of knowledge articulates these interruptions in terms of 'good' and 'bad' gameplay areas, and decision-making may be enhanced by augmenting the runners' gameplay interface to dynamically reflect coverage and promote situational awareness. The handling of interruptions also relies on diagnostic work, where runners collaborate to establish the gameplay status of other runners. This enables them to determine the generality of interruptions and to take appropriate action. Diagnostic work may further be supported by augmenting the runner's interface with status information to promote remote surreptitious monitoring

Ultimately, our study suggests that decentralizing support is not simply a matter of supplying 'ground workers' with control room information, but of transforming such information by embedding it in *representations that are relevant and responsive to the situated and methodical ways in which interaction is ordinarily orchestrated 'on the ground'*. Accordingly, we have considered several extensions to our game technology to enhance 'on the ground' orchestration work. This includes providing runners with dynamic colour maps that show both past and predicted coverage of WiFi and GPS; showing status information of other runners, including last known state following disconnection; and exploring fall-back solutions for wireless networking and positioning. Future work will explore these techniques in practice to see whether they can enhance the orchestration of our particular game, and potentially other location-based games and mobile and context-aware experiences.

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