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ORIGINAL ARTICLE

Hybrid ecologies: understanding cooperative interaction in emerging physical-digital environments

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Abstract We consider the emergence of hybrid ecologies, which marry mixed reality environments and ubiquitous computing environments together to bridge the physical-digital divide. Hybrid ecologies are new class of digital ecology that merge multiple environments, physical and digital, together. Collaboration in these emerging environments is characterized by 'fragmented interaction' in that it is mediated by interaction mechanisms that are differentially distributed. Unpacking the collaborative nature of fragmented interaction requires that we uncover the ordinary interactional competences that users exploit to make differentially distributed mechanisms of interaction work and the distributed practices that articulate 'seamful' representations and provide for awareness and coordination.

Keywords Cooperative interaction · Ethnography · Ecology · Mixed reality environments · Ubiquitous computing environments · Hybrid ecologies

1 Introduction

The ecology of work has played a central role in understanding cooperative interaction. By 'ecology' we refer to the space or environment that cooperation takes place within and to the socially organized ways in which the environment affords collaboration. Early studies of cooperative interaction drew attention to the significance of the ecology. Air Traffic Control [25], for example, showed how the control room was socially organized to support collaboration in large part through the ecological distribution of flight strips, and a host of other ethnographic studies (e.g. [8, 11, 33]) have shown how people exploit ecological arrangements to integrate and align their interdependent activities in a range of other settings as well. Over the years researchers have explored the development of a range of *digital ecologies* to support cooperative interaction. The development of digital ecologies has been embedded in two main strands of research: one that is predicated on models of face-to-face collaboration, which has seen the emergence of media spaces [5], dual ecologies [30] and mixed ecologies [29]; the other predicated on spatial models of collaboration, which has seen the emergence of collaborative virtual environments [2] and mixed reality environments [28] on the one hand, and graphical interfaces that exploit spatial metaphors [35] on the other.

The emergence and growing shift towards ubiquitous computing has seen digital technologies become increasingly embedded in the physical world that we inhabit. This has been manifest in a range of environments that combine mixed reality environments with ubiquitous computing infrastructures, applications and devices to support collaboration across the digital-physical divide [1, 5, 6, 12]. The resulting environments are both geographically distributed and merge interaction across physical and digital environments to form *hybrid ecologies*. Understanding the nature of cooperative interaction within digital ecologies has been a

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longstanding concern within IT research (e.g. [15, 21, 22]). The emergence of a new class of interactive environment that spans the physical-digital divide warrants similar attention and is a major challenge for the ongoing development as computing moves away from the desktop and the workplace to disappear, with appropriate reservation [41], into the fabric of everyday life [42].

In this paper, we wish to explore the concept of 'hybrid ecologies' as a way of understanding the nature of cooperation in emerging environments, which merge physical and digital interaction. Our aim is to provide a means for analysts to approach the study of cooperative interaction in these environments by outlining fundamental features of interaction within them. A particular concern in this endeavour is the *fragmented nature of interaction* brought about through different and differentially distributed mechanisms of interaction. We ground our exploration in an ethnographic study of a particular hybrid ecology to illustrate these issues before moving on to consider issues of more general concern. Of particular relevance here are the ordinary interactional competences that users exploit to reconcile 'fragments of embodied virtuality' [42]—and so make differentially distributed mechanisms of interaction work—and the distributed practices and 'seamful' representations [10] that articulate the links between wired and wireless networks to provide for awareness and coordination in emerging digital environments.

2 Illustrative hybrid ecology

The central purpose of this paper is to elaborate the collaborative nature of emerging hybrid ecologies. We unpack the notion, and the fragmented character of interaction that defines it, by reflecting on an ethnographic study of a mixed reality game called *Uncle Roy All Around You* [4].[1] In this analysis we are less interested in the playful or performance aspects of the game. Rather, our interest is in what the game might tell us about interaction in emerging physical-digital environments. Deployed in the wild, the game is of methodological value insofar as it provides a 'perspicuous setting' [18] where the real world, real time sociality of technology use might be readily observed. Essentially, publicly deployed experiences such as *Uncle Roy All Around You* provide a safe environment in which to explore the cooperative character of emerging technologies [13]. Below we provide an overview of the experience before exploring the ways in which players exploit hybrid ecological arrangements to achieve cooperative interaction across the physical-digital divide, in this case online and on the streets.

2.1 Uncle Roy All Around You

Uncle Roy All Around You is a public event where online players must work with players on the streets of a city to locate the office a fictional character called Uncle Roy. As a research endeavour this work extends prior research into the affordances of mobile and location-based technologies based on GPS and WiFi [16] and the collaborative ways in which the technology was made to work [12]. *Uncle Roy All Around You* explores a 'self-positioning' approach [3] where mobile users (street players) report their positions. They do this in two ways: by explicitly declaring 'I am here' on an electronic map on a mobile device (a PDA) in order to receive a new clue from the game server, and implicitly through their use of the map as they follow clues through the game space (~1 km^2 of a city). The map only enables street players too see a limited area of the overall game space at any moment and they have to drag the 'me' icon across the map to pan this view, which implicitly reports their position (Fig. 1).

Implicitly and explicitly self-reported positions are represented in different ways to online players, who track a street player's movements in a parallel virtual environment. The implicit positions of street players are represented through a pulsing sphere (Fig. 2) and

Fig. 1 The street player's interface

[1] www.blasttheory.co.uk/bt/work_uncleroy.html

Fig. 2 The online player's interface showing implicit position of a street player

explicit positions are represented through a spiky sphere (Fig. 3). Online players, who are represented in the virtual city by an avatar, can also see a photograph of street players (right of Figs. 2, 3) and can communicate with street players and other online players via text messages. Street players communicate with online players by sending short (7 s) audio messages via the PDA. Street players and online players must collaborate to find a postcard that is located somewhere in the physical city. Each online player must find a particular postcard, any card will not do. When the right postcard is found information is sent to the online player, which he or she uses to guide the street player to Uncle Roy's office.

A third interface is located behind-the-scenes in a control room (Fig. 4). It displays street players biographies (their names and a description of their appearance and clothing) their location in the game space, where they are on the clue trail, who they are talking to online, and their connectivity status. Control room staff draw upon these resources to orchestrate the game, exploiting them in particular to assist three street performers whose task it is to handle contingencies on the street. Front of house, control, the office

Fig. 3 The online player's interface showing the explicit position of a street player

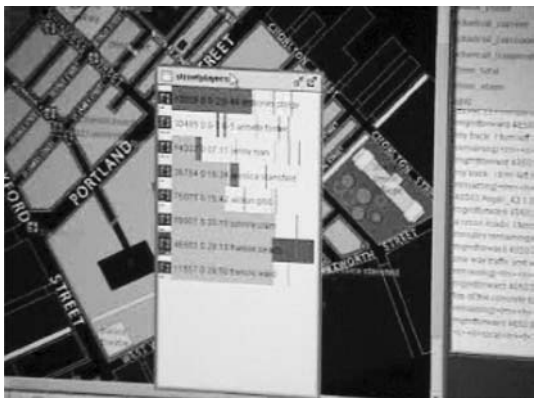

Fig. 4 The control room interface shows player descriptions, locations and connectivity status

and street performers are all in contact with another via walkie-talkies.

The challenge of understanding cooperative interaction in such an environment is to understand how the participants embed the different interfaces in interaction so as to provide for the achievement of effective collaboration. This requires them to reconcile the various fragments of interaction 'at work' in the game, such as audio messages and text messages or connectivity readings, reported locations and clues. Below we present a series of vignettes from an ethnographic study to illustrate the fragmented nature of cooperation between players and between behind-the-scenes staff.

2.2 Collaboration between players

A 5-min sequence of interaction presented in this section illustrates the situated nature of cooperation when things run smoothly. Recovering this sequence required some effort on behalf of the field worker. It was produced by shadowing a street player, videoing his actions and by extracting and synchronizing messages from system logs with video recordings to thicken the description of interaction and explicate its cooperative features [14]. Bold text in the vignettes indicates the contents of audio files sent by street players and italic text indicates the contents of text messages sent by online players.

Segment number 1 of the sequence is indicative of the work that goes into making sense of clues provided by Uncle Roy and shows that the interpretation of clues exploits a player's local knowledge of the physical ecology. In this case, the game is physically located in Manchester (in the north-west of England). Like many player's, Patrick is from the local area and knows that China Town is a prominent landmark in the city, that it is somewhere nearby, that the clue is to be read as a

direction to another location from where he is now, and that given the content of the clue, China Town is a reasonable candidate for the next location to which he must make his way.

Number 1 (Start time: 20.17.45) Patrick has just declared his position and received a new clue — Wai Yin. Translate: men cannot enter. Make appropriate move. (23 minutes remaining)
Patrick: Wicked, right, China Town. He starts walking, looking at his PDA as he moves off.

The main part of the sequence shows us something of the work that occurs in the intersection of following a clue and finding a postcard. Segment number 2 shows that collaboration between players is often initiated through the co-production of greetings. The doing of greetings, while relatively trivial, is indicative of the ordinary ways in which collaboration online and on the streets proceeds.

Number 2 Nicole: *Hi Patrick, that jacket looks cool.*
Patrick laughs: Someone's telling me I've got a nice jacket on.
Patrick selects audio record: ''Thanks **Nicole, it's very comfortable and it's keeping me very warm tonight, so thanks for that.**''
Patrick: It's bizarre in it.

Initiating collaboration online intersects with the work of following a clue, which continues in ordinary ways on the streets. Having determined what his destination is, the player must find his way to it and, as we can see in segment number 3, an ordinary method of way-finding consists of exploiting other people's local knowledge. Following a clue by asking others the way and by subsequently being instructed in the way is a method of navigation commonly employed by street players and what engagement with the game relies upon to some extent.

Number 3 Patrick turns towards a man and woman walking towards him: Excuse me? Do you know where China Town is?
Man: That way (points to a street across the road).
Patrick: Right down there (Charlotte Street). Wicked. Cheers mate.
Patrick: It's where there's the big gate.
Patrick crosses the road and looks at his PDA.

Ordinary methods of way-finding are also exploited online to get the work of finding a postcard done. In segment number 4, Dave issues Patrick with an instruction but it lacks ecological validity as it were [20]. It is not clear from Patrick's position on the streets where the graffitied phone box or the railings that he has been directed towards are and he asks Dave to clarify the instruction. The request for clarification is framed in terms of Patrick's ecological relevancies—his current physical location and what to look out for from here. Despite its practical inadequacies, Patrick does not disregard the instruction but reads it for its instructable features and scans the physical ecology for potential candidates, such as the red phone box on Reyner Street.

Number 4 Dave: *Go into the graffitied phone box by the railings.*
Patrick: Right, Dave's just sent me a message - ''Go into the graffitied phone box by the railings.'' So I'm going to send him a little message now.
Patrick stops walking down Charlotte Street at the junction to Reyner Street.
Patrick selects audio record: ''Dave, **can you direct me to it. I'm outside the red phone box outside er — oh bollocks** (looks around for a street sign) – **outside Reyner Street**. So yeah, if you want to direct me there that would be wicked. Cheers mate.''
Patrick crosses Charlotte street and heads towards a red phone box on the other side. He stops outside the phone box and checks his PDA again.

The work of instruction continues in segment number 5 as the players seek to locate a postcard. It consists of directing the street player to search a location on the one hand and, if the search is successful as it is here, in eliciting personal information from an online player as per the postcard's instructions.

Number 5 Dave: *Have you found the postcard on top of the phone.*
Nicole: *Hi Patrick, my postcard is at this phone box. There is something on top of the phone box.*
Patrick: Is he trying to goose me here. He's telling me that I've got to have a look on top of the phone box. And Nicole, who likes my jacket, is saying that her postcard's here as well.
Patrick opens the phone box and looks inside: There's nothing in there.

Patrick looks around and notices a postcard on the floor outside the phone box, which he picks up.
Patrick: All right. It says tell me about someone from your past who never leaves you. Right, OK.
Patrick: Right - he selects audio record — ''Nicole, **tell me about someone from your past who never leaves you. That's what it says on your postcard** and it's on - he looks around for street sign - Charlotte Street.''

Segment number 6 shows how online players clarify prior instructions to respond to a street player's ecological relevancies by providing the street player with a concrete destination: the phone box on Portland Street by the tower, rather than the graffitied phone box by the railings. Again the player exploits his local knowledge of the physical ecology (and where the player's local knowledge fails, then the local knowledge of members of the public may be consulted instead) to follow the instruction and makes his way towards Portland Tower (which is just at the bottom of Charlotte Street). And again, the instruction is read for its instructable features and the physical ecology is scanned for potential candidates. Two phone boxes on Charlotte Street adjacent to Portland Tower are identified as potential candidates and Patrick asks Dave to confirm their candidacy while proceeding on his way to Portland Tower.

Number 6 Dave: *You need the phone box on Portland Street by the tower.*
Patrick, looks at PDA: Right, and apparently there's another one. There's a phone box - Dave's telling me there's a phone box over by Portland Tower. Having just come from there, Patrick knows where Portland Tower is and so he turns around and heads towards it.
Patrick comes across two more phone boxes on Charlotte Street across from Portland Tower: Ah right. He selects audio record — ''Dave, **is it the one over the road from Portland Tower**.''
Patrick walks around the phone boxes and stops to check his PDA. He then continues on his way towards Portland Tower, stops to cross the road and checks his PDA again.
Dave: *OK mate well done. I'm waiting for directions.*
Patrick: Well I've just got a well done from Dave.

Along the way, and as segment number 7 shows, Patrick is obliged to clarify the meaning of the retrieved postcard to Nicole.

Number 7 Patrick is still looking at his PDA.
Nicole: *Huh ... um someone from my past ... is it a riddle.*
Patrick selects audio record: ''No Nicole. **Nicole, it's not a riddle. It's - er - it's the clue that's on the postcard on the - er - Charlotte Street phone box**. Do you want to text me the name of someone from the past who never leaves you.''
Nicole: *OK my best friend Royce. He is so great and has always stuck by me.*

After complying with the request to provide personal information, Uncle Roy will provide Nicole with instructions to guide Patrick to his office. First however, and as we can see in segment number 8, Uncle Roy needs to know where Patrick is and he instructs Patrick to declare his position. It is not that Uncle Roy (or control room staff in this case) thinks that the player is lost but that he is aware that the player is being distracted. Patrick has already located a postcard for an online player and he does not need to find another one. The pursuit for further postcards is leading Patrick astray and there is a need to get him back on track before time runs out.

Number 8 Patrick crosses the road in front of Portland Tower, heading towards another phone box and checks his PDA again.
Uncle Roy: Where are you? Press ACTIONS then choose I AM HERE to let me know. (18 minutes remaining)
Patrick: Right, Uncle Roy's getting a bit annoyed because I'm not telling him where I am. Patrick declares his position and receives another clue furnishing him with further instructions. (End time: 20.22.48)

2.2.1 Some salient features of collaboration

While there is a great deal more that could be said the vignettes we have offered above illuminate something of the essential nature of collaboration across gameplay. In the first instance we can see that following clues and finding postcards are not separate activities but intersect and overlap. Furthermore, both are done through ordinary methods: exploiting local knowledge

to interpret clues and to navigate the physical ecology and to coordinate the search for postcards through instructions and clarifications. Search and find instructions and clarifications are *essentially ecological in character*. In all their variations they revolve around formulating adequate directions to places and objects and coordinates locating places and objects. While online players track street players through a virtual facsimile of the street player's physical ecology the two parties do not share the same orientation to places and objects. Successful collaboration relies upon players' ability to establish a mutually intelligible orientation to places and objects. Instructions are not sufficient in themselves to establish this, however, as they lack ecological validity and cannot do otherwise given the asymmetry between the players' ecologies. The ecological validity of instructions is practically resolved, and mutually intelligible orientations achieved, through clarifications framed in terms of ecological relevancies, the identification of candidate places and objects, and the subsequent reformulation of instructions furnishing coordinates that align street players and online players orientations.

It is notable, however, that ordinary methods of communication between players in this sequence are underpinned by considerable *communicative asymmetry*. Communicative asymmetry has been widely reported as a problematic issue for media spaces [24, 31]. However, it appears not to be a problem here in anything like the same way. The asymmetry may certainly cause practical difficulties on occasions where players struggle to establish a mutually intelligible orientation. However, over 80% of players found their way to Uncle Roy's office, which suggests that like Patrick a great many players are more than capable of handling the problem. The reason for this is that unlike media spaces, collaboration here is mediated through different mechanisms of interaction: mobile devices and audio messaging on the one hand and a virtual environment and text messages on the other. While these mechanisms produce the asymmetry they do not 'disrupt' interaction [23], as there is no symmetry to disrupt in the first place, rather they 'fragment' it. By that we mean that *interaction is distributed across distinct ecologies*—in this case, one physical and one digital—and that it is mediated by two different communication channels: audio and text. From the outset players must reconcile the fragments to align their interdependent activities, which they do in essential ways through establishing the ecological validity of instructed actions.

2.3 Collaboration behind-the-scenes

Over the course of the game contingencies arise that impact on gameplay and require some form on intervention. There is a need, then, for a street player's progress to be monitored and this is done through behind-the-scenes work that is for the most part invisible to street players. Monitoring is provided for by the distribution of three street performers at particular vantage points around the physical gameplay area and trades, in the first instance, on their ability to recognize players. This might seem a relatively mundane and straightforward matter of 'seeing a person carrying a PDA'. However, recognizing a player is more complicated than that as the game takes place on busy city streets where it is not at all uncommon for people to be walking around with mobile devices in hand, such as phones, MP3 players, PDAs, etc.

There are several interrelated ways in which recognition is achieved, first of which is through instructed looking. In the course of induction into the game, front of house broadcast that new players are entering the game via walkie-talkie. While front of house's talk is usually directed to staff in the control room, it also serves to announce to street performers that new players will soon be coming out onto the streets:

> Front of house: Front of house, we have 3 players in the game - Katherine, Kate and Paula.
> Control: All 3 PDAs are connected front of house.

By listening to messages from front of house street performers know that players are connected and that they should start scanning the streets for them.

It may be the case, of course, that in scanning the streets, performers recognize player's at-a-glance. This consists of seeing people doing such actions as carrying a PDA and a stylus, interacting with the PDA via the stylus, talking into the PDA, and aligning the PDA with their surroundings, visibly navigating the streets around them. To the attuned eye players may be recognized hundreds of feet away on busy streets and not only when they are 'in your face'. However, it is not always possible to recognize player's at-a-glance, whether at a distance or up close as the following vignette indicates:

> John is watching a woman as she walks down Whitworth Street. She turns right down Princess Street, which will take her out of the gameplay area if she is playing the game.
> John (not on walkie-talkie): I don't think she's one of ours – it didn't look like a PDA she had there. Might have to just check.

John: John to control.
Control: Go ahead.
John: Can you just confirm whether one of the girls was Asian, over?
Front of house: Front of house to control, none of the women was Asian.
John: It's OK. Don't worry, over.

This vignette shows that recognizing a player, or someone who might be a player but turns out not to be, exploits an arrangement of collaboration between the street performer, control and front of house. That arrangement is mediated by walkie-talkie communication and exploits online player descriptions assembled during induction, which are available to both front of house and control (either could have responded to the performer's query and so too could the office).

It is also the case on occasion that players are simply not recognized on the streets. They do not pass unnoticed, however, even though they have not been seen.

John is scanning Whitworth Street, looking for a player whose release was announced some time ago. He broadcasts the news on his walkie-talkie that he has not seen David come past him yet and then walks down the street searching for him.
Caitlin (another performer): John, did you find him?
John: No, but he's not on Whitworth Street. I'm just wondering whether he's gone out the wrong way on Whitworth Street or Oxford Street, over.
Caitlin: Yep, I'm going to go that way. I'm on Portland Street now. Do you want to stay in the game and I'll walk down those two streets.

The vignette indicates that street performers have a sense of how long it should take a player to come into their zone and failure to comply with this expectation—failure to recognize a player having been instructed to look—triggers an unfolding course of work exploiting various arrangements of collaboration that transforms the player into a lost object to be found within the physical setting of the street. In the first instance, failure to recognize a player leads the performer to notify other performers and behind-the-scenes staff of the situation. Performers then move beyond scanning the street from a particular vantage point to trace the player's expected pathway through the game space. This entails walking the streets the player is expected to be on and scanning them to establish whether he or she is there or not. If it is established that the player is not where he or she should be then potential pathways the player might have taken are considered and the performers concert their actions via walkie-talkie to execute the search:

Caitlin to another street performer: I want you to check around G8, around that area, for a guy called David. He's the only male player with a PDA in the game. Can you just go up there, he may be up there, I might have missed him.

Street performer: Head down to Portland Street, that area?
Caitlin: Don't come down onto the south-side. Stay on the north, 'cause we're down south.

In addition to the walkie-talkies street performers employ grid references (e.g. G8), which are detailed on a small card that each performer carries and are also displayed on the gameplay interface in the control room, and used to concert the search for lost players. G8 is in the middle of the gameplay area and a location that provides 'good views' across large sectors of that area. As such, performers often go there to look for lost players. Nevertheless, if tracing a pathway or potential pathway fails to locate a player, performers must resort to trawling the streets to find someone who might be and indeed is a recognizable 'player'. Then, of course, as a last resort there is always sheer serendipity.

The concerted search for lost players does not always run smoothly, as the following vignette indicates when a player (Yasmeen) is not recognized following the scanning of pathways and trawling the streets:

John: Can you just reconfirm her description, over?
Control: Yasmeen is female, middle-aged, long black hair, brown blazer, blue jeans.
John walks back to his vantage point looking out for Yasmeen on the way.
John: John to Caitlin. Are you sure she's not going down Whitworth Street West and still playing the game as if she's was in the area, over?
Caitlin: Caitlin to Martin (control), can you give me an update on Yasmeen please?
Control: She's in K11. I don't think we need to find her.
Caitlin: I don't think so either John, I think she's fine.
John: She's not in K11. I'm standing there now. She's nowhere near that area. It's the car park area K11 and there's no one of that description, over.
Caitlin: She's still connected and she's still playing – I think she's fine.
Control: She's getting clues.

Yasmeen did not get lost as it happens but the experience of trying to find her shows more of the collaborative arrangements and cooperative practices through which 'losing a player' is handled. In situations

where players have not been recognized on the streets, then they may be recognized virtually through digital traces showing location, connectivity status and clue trail. Digital traces are provided by control's view of the game. That the player is reporting location, connected and 'getting clues' settles the matter: the player is not lost but in the game and 'fine'.

Recognition practices are central to monitoring players. Recognition is not simply a matter of seeing in various ways that players are playing the game or that they are lost, but also, of recognizing that they are 'confused', as the following vignette elaborates:

> John (not on walkie-talkie): There's one now, heading towards us in green.
> John (not on walkie-talkie): Looks like she's a bit confused.
> The player is standing in street, looking at the PDA and at her surroundings. John is about 50 metres away, monitoring her actions. The player turns and starts walking towards John. She stops again, turning around and looking at her PDA and her surroundings.
> John (not on walkie-talkie): Right, I'm going to – oh no, she's off.
> The player sets off back in the direction she has come.

This vignette shows that while consulting the PDA and her surroundings, the player's accompanying actions, particularly her changing orientation to the streets, suggests to the street performer that she is encountering some kind of practical trouble that is 'confusing' her. The vignette also shows us that recognizing confusion is not as straightforward as it might first appear. That the player looks confused because of her changing orientation to the streets—particularly her changing bodily orientation (from left to right, back to front, etc.) and constant consultations with the PDA that accompany these bodily orientations to the street—does not mean that she is confused. Or rather, and more to the point, such outward signs of confusion do not mean that the player is encountering an obdurate trouble that is likely to effect the playing of the game.

The nature of confusion only becomes apparent to street performers after watching an unfolding series of player actions on the street and it is with this knowledge in mind that street performers often exploit a practice of shadowing players, monitoring them from a distance and following them around if needs be, to establish the state of confusion being encountered. Shadowing a player is a covert activity that involves collaboration with control and other behind-the-scenes staff. The primary purpose of this collaboration is to find out if the player is experiencing any obvious technical difficulties or that the state of confusion is interpretive in character: that the player has taken an incorrect bearing and aligned the map wrongly, misinterpreted the clue, is trawling the streets to develop enough knowledge to make sense of the clue's instructions, or is quite simply and utterly lost. Collaboration with others in the division of labour allows performers to rule in or out technical sources of confusion, then, and to elaborate candidate sources of 'confusion'.

Recognizing confused players is essential to gameplay—in the absence of such recognition, play would breakdown, players would get lost and find themselves stranded and alone in the city. Recognizing confusion not only warrants investigation then but intervention as well, which prevents terminal breakdown. Intervention is done for three main reasons: to keep or put the players back on track, to remedy technical faults, or to address contraventions to the 'rules of the game', typically where two or more players collaborate having purchased only one ticket and share one PDA without prior consent (consent would be given to parents with children, for example, but rarely for adults). Whatever the case, intervention relies on collaboration with control, and the technologies at his disposal, and with other performers to locate players and determine the most appropriate course of action.

2.3.1 Some salient features of collaboration

Cooperation between players is complemented by collaboration behind-the-scenes, which is concerned to handle the contingencies that effect the following of clues and finding of postcards. Those contingencies revolve around problems of orientation, where street players align the map wrongly, go off track, get lost and even walk out of the game zone; problems of interpretation, where players have insufficient local knowledge to make sense of a clue or an online player's instructions; and technical problems, where the street player's equipment breaks down in various ways. Contingencies are handled through a family of recognition practices that provide, when needs be, for effective intervention. These recognition practices consist of and are achieved through arrangements of collaboration between street performers and other behind-the-scenes staff. They are *distributed across distinct physical ecologies*—on the streets, front of house, control and (occasionally) the office—and they *combine with a digital ecology* that marries player biographies with information from the online gaming environment and feedback from the GPRS network.

Recognition practices merge these physical and digital ecologies together to enable behind-the-scenes staff to produce and maintain awareness of a street player's status and to coordinate staffs' actions appropriately. Players are 'monitored', then, through combining physical and digital ecologies to *produce and maintain awareness* of their current status across the division of labour. As we have often seen before in CSCW, awareness is a core feature of collaboration [38]. Furthermore, ethnographic studies have shown how the ecology of work plays a crucial role in the production and maintenance of awareness, how it relies on the movement of working objects around the ecology and how this enables people to track the flow of work [25]. In effect, the movement of objects around the ecology creates a shared representation of where in the work right we are right now, what needs to be done next, what troubles are to hand, what is on track, outstanding, and so on [26].

However, ethnographic studies have largely focused on the ecological production of awareness in physical ecologies where people are co-located but awareness in Uncle Roy *blends physical and digital ecologies* where people are distributed. Consequently, while the production of awareness here also relies on the movement of objects (in this case, street players) through the physical ecology, movement is not only physical but digital: on the one hand we have physical movement through the streets and on the other, digital traces of movement in the physical ecology and of play in the virtual ecology. Only control has a representation of movement to work with, street performers must appeal to the streets to see where in the work things are now and fall back on control's representational account where that fails, which it inevitably does because players' work is distributed across physical and digital ecologies. Representation of the movement of working objects is fragmented and differentially distributed then. Behind-the-scenes staff must work together to reconcile the fragments and provide for the effective monitoring of players. That work is done through the constant production of accounts (status requests, queries, assistance calls, player descriptions, reports of what's happening online, etc.) whereby their recognition practices are articulated and monitoring is coordinated.

3 From hybrid spaces to hybrid ecologies

We have suggested through our reflections of Uncle Roy the emergence of hybrid ecologies that span and merge physical and digital spaces. We have also implied that there is something distinctive about these arrangements. In this section we wish to reflect on what this distinction might be and why it may be important. In order to do this we shall take as our starting point the notion of 'hybrid spaces', which has existed in one guise or another across media spaces, mixed reality and ubiquitous computing.

The notion of hybrid spaces was initially offered as a characterization of media spaces in reaction to the face-to-face baseline against which they were evaluated and found wanting [15]. The suggestion was that the media spaces comprise both virtual and physical spaces and so create a hybrid space:

> ''When two offices are linked together in a media space, then a hybrid space is created; it involves not only the virtual space of the media connection, but also the real physical space of the two offices.'' [22]

The emergence of mixed reality systems went beyond linking physical spaces through digital mediums to 'fuse real and virtual spaces together' [32]. Mixed reality systems exploit 'hybrid models' of space [39] to create environments that augment the physical and digital and are seen to move along a virtuality–reality continuum, from CVEs towards 'tangible bits' [27]. Ubiquitous computing environments extend this further by embedding computing into the wider physical environment. They exploit invisible sensing infrastructures to create 'hybrid networks' [43] that situate computing in a multitude of locations and devices, some in the physical fabric of the built environment [40], others mobile and carried on the person [36]. Ubiquitous computing environments 'embody virtuality' [42] in a burgeoning array of low-cost, low-power, wireless devices that embed computing in the physical fabric of everyday life.

Hybrid ecologies combine and exploit the affordances of mixed reality and ubiquitous computing environments to extend the purchase of computing across multiple environments, physical and digital. We would suggest that they extend the virtuality–reality continuum and span environments that Weiser considered to be 'diametrically opposed' (ibid.), combining hybrid networks and ubiquitous devices with hybrid models of space and collaborative virtual environments to create collaborative spaces that merge the physical and the digital.

Throughout the history of design, and across their various incarnations, hybrid spaces have been treated as a special class of space with unique qualities or affordances that promote and support collaboration. Thus, and for example,

- Media spaces LINK physical spaces through digital mediums.
- Mixed reality environments FUSE physical and digital environments.
- Ubiquitous computing environments EMBED the digital into physical environments.
- Hybrid ecologies MERGE multiple environments, physical and digital.

'Linking', 'fusing', 'embedding' and 'merging' are not just words but words that represent the movement of computing away from the desktop to distribute computing in a multitude of real and virtual environments.

3.1 Articulation work

The development of new computing environments gives rise to new forms of collaboration, not only in terms of how people engage in everyday activities together but also in terms of how they *articulate* collaboration [37] and so make novel computational environments work in the 'here and now' for the practical purposes to hand. It is in articulating collaboration that 'links' are made between environments, that digital and physical environments are 'fused', that the digital is 'embedded' in the physical, and that multiple digital and physical ecologies are 'merged'. Each stage of the movement of computing away from the desktop is characterized by the unique nature of articulation work. Thus, and for example,

- Media spaces rely on the articulation of face-to-face interaction (e.g. [23]).
- Mixed reality environments rely on the articulation of spatially organized interaction (e.g. [17]).
- Ubiquitous computing environments rely on the articulation of context-aware interaction (e.g. [7]).
- Hybrid ecologies rely on the articulation of 'fragments of embodied virtuality' [42] or fragmented interaction.

While collaboration in media spaces, mixed reality environments, ubiquitous computing environments and hybrid ecologies might not normally be thought of in terms of articulation work, studies of these technologies in use exhibit essential features of articulation work whether paid labour is at stake or not. As Schmidt and Bannon [37] put it,

> ''cooperating workers have to articulate (divide, allocate, coordinate, schedule, mesh, interrelate, etc.) their distributed individual activities.''

This, of course, is what we find when we look at collaboration across physical and digital spaces in all their variety as articulation work is a necessary 'overhead' (ibid.) of collaboration wherever and however it occurs.

3.2 Fragmented interaction

What is of concern to design is the distinctive or uniquely adequate character of articulation work in physical and digital spaces. In hybrid ecologies collaboration is distinctively concerned with the articulation of fragmented interaction. By fragmented interaction we mean that collaboration in hybrid ecologies is mediated by different mechanisms of interaction, which are differentially distributed among participants. Thus, different participants employ different mechanisms of interaction to collaborate, which means that a degree of interactional (including communicative) asymmetry is built into collaboration in hybrid ecologies.

We should, of course, be careful of the hype that attaches itself to new technologies and technological arrangements of collaboration. Collaborative activity, as Chalmers [9] points out,

> ''continually combines and cuts across different media, interweaving those media and building up the patterns of association and use that constitute experience and understanding.''

There is nothing inherently new about fragmented interaction, then, it inhabits collaboration everywhere as we switch between digital and physical media in course of our everyday activities. What is new, however, is the way in which collaboration is provided for in hybrid ecologies, through the interweaving of hybrid networks and hybrid models of space, and how mechanisms of interaction are articulated in hybrid ecologies.

Our study of *Uncle Roy All Around You* suggests that fragmented interaction is articulated in two fundamental ways in hybrid ecologies:

- Through the exercise of ordinary interactional competences.
- Through the use of digital representations of action and collaboration in real and virtual environments.

By ordinary interactional competences we refer to what Garfinkel [19] calls 'vulgar competences' or taken for granted competences that people methodically exploit (or use time and time again) to orchestrate their activities—competences such as requesting clarifications to establish the ecological validity of instructions. While examples such as this are situated, particular and very much tied to the technological arrangements

constitutive of *Uncle Roy All Around You*, the exercise of vulgar competence is of more general relevance to understanding collaboration in emerging physical-digital environments. Vulgar competences are part and parcel of the 'working knowledge' that technology use relies upon [26]. Through them participants reconcile the differentially distributed fragments whereby interaction is expressed in hybrid ecologies and through them we come see how the technological mechanisms of interaction that populate hybrid ecologies are 'made to work' to afford collaboration.

3.3 Seamful representation

The collaborative nature of representations in emerging physical-digital environments is an issue of some significant relevance to design. Of particular note is what Weiser [42] called the 'transparent linking of wired and wireless networks'. In more recent times this has been called 'seamful' design [10] where representations are designed to reveal the status of hybrid networks and make it available as a resource for interaction (such as monitoring players). Historically, however, seamful design has focused on revealing breakdowns (e.g. GPS or WiFi black spots), but as Weiser's characterization suggests (with its emphasis on transparent linking) there is no need to restrict representation to occasions where invisible sensing systems become visible. On the contrary, Weiser's characterization seems to open up the possibility of a broad set of representations that span wired and wireless networks. There is, then, no inherent need to limit seamful design to representing network connections and breakdowns in invisible sensing.

Representations in *Uncle Roy All Around You* make links transparent at a number of interconnected levels. Naturally the GPRS connectivity of players is represented and sits alongside representations of player's position in the game zone. These representations are complemented by others with which they overlap. Thus, the status of interaction in the online gaming environment is also represented in terms of the clues a player is receiving from the game server and the messages players are sending to one another. These representations span wired and wireless networks and make the links between them transparent. They suggest that seams might be more usefully understood as representations where different but complementary views on interaction coexist [34]. Such representations enable behind-the-scenes staff to go beyond breakdowns and provide for the traceability of players.

Seams might more closely approximate what are traditionally thought of as 'mechanisms of interaction',

> ''in the sense that they 1) are objectified in some way (explicitly stated, represented in material form), and 2) are deterministic or at least give reasonably predictable results if applied properly.'' [37]

Like the use of less formal mechanisms of interaction, such as text and audio messages, representations 'themselves require articulation work' (ibid.). Without labouring the point, that work is done in this case through the constant production of accounts constitutive of the recognition practices involved in monitoring players. While these recognition practices and the representations they exploit are situated and particular we might, nevertheless, venture the observation that hybrid ecologies permit new forms of representation to underpin awareness and coordination in future and emerging technological environments.

3.4 Putting the concepts to use

We do not offer these observations and concepts as a panacea to the thorny problem of understanding emerging physical-digital environments. We are not saying all UbiComp has to do is subject the novel mechanisms of interaction that hybrid ecologies exploit to ethnographic study and thereby explicate the articulation work that provides for the reconciliation of fragments of interaction and the realization of cooperation. We are saying that such an approach will help UbiComp researchers recognize the some of the core challenges that emerging hybrid ecologies present to our understanding, however. What we offer here is not a body of findings then, but the identification of some salient topics for ongoing investigation. Just as it has taken many years to understand the nature of cooperation in the workplace, it will take many years to unpack the nature of cooperative interaction in hybrid ecologies.

We propose *articulation work*, *fragmented interaction* and *seamful representation* as core topics insofar as they are essential features of cooperative interaction in hybrid ecologies. While there is nothing inherently new about articulation work, fragmented interaction and the use of representations as mechanisms of interaction generally, their local, historical and material instantiation and composition is new insofar as they are tied to new technological arrangements that permit new forms of collaboration that span and merge multiple physical and digital ecologies. Furthermore, understanding how novel interaction mechanisms are articulated across multiple physical and digital ecologies is essential to understanding the collaborative character of emerging

physical-digital environments and, thereby, of informing design. Articulation work is particularly key in this regard as it reveals how hybrid ecologies are collaboratively embedded or situated in the real world and what the 'situating' turns upon or relies for its concerted achievement. The uncovering of articulation work enables developers to determine what may and may not be automated and what may or may not left to human skill and judgement.

In the case of *Uncle Roy All Around You*, further automating the monitoring of players, for example, would not be profitable. It is not only that reliance on digital traces may be misleading—it is perfectly possibly for a player to have left the game zone but declare his position within it, for example—but that automation would fracture awareness across the division of labour. The production and maintenance of awareness upon which monitoring relies does not derive from any single source, physical or digital but on the distribution of people at various locations who exploit various resources, social and technical. The use of these resources is embedded in the continuous flow of accounts emerging from the multiple locations where behind-the-scenes staffs are situated, which provide for and reflexively distribute awareness. Further automating monitoring by providing each performer with direct access to seamful representations, for example, would disrupt the flow of accounts then and fracture the production and maintenance of awareness upon which gameplay ultimately relies.

We do not suggest that these are in and of themselves particularly profound design insights but rather, that in confronting the new we also encounter something of the familiar. Understanding interaction in hybrid ecologies will consist, then, of understanding such things as how awareness and coordination 'get done'. However, the distinctive nature of cooperation in hybrid ecologies will requires of us that we unpack the ways in which the doing of such things as awareness and coordination, and other essential features of cooperation, are *different*. The suggestion here is that cooperative interaction is essentially fragmented by different and differentially distributed mechanisms of interaction in hybrid ecologies and that their use relies on articulation work, which elaborates the distinctive character of emerging physical-digital environments.

4 Conclusion

We have suggested that understanding the ecology of work has been a perennial feature of IT research and that ethnographic studies of physical ecologies have been complemented by efforts in design to develop digital ecologies. The development of digital ecologies has been marked by three distinct strands of research. First, media spaces; second, collaborative virtual environments and mixed reality environments; and more recently, *hybrid ecologies* which marry mixed reality environments and ubiquitous computing environments together to bridge the physical-digital divide.

Distinctively, media spaces 'link' physical spaces together through digital mediums; mixed reality environments 'fuse' physical and digital environments together; ubiquitous computing environments 'embed' the digital into physical environments; and hybrid ecologies 'merge' multiple environments, physical and digital. Understanding the nature of cooperative interaction within digital ecologies has been a long-standing concern within design and the emergence of a new class of interactive environment that spans the physical-digital divide warrants similar attention as computing moves away from the desktop and the workplace to disappear into the fabric of everyday life.

An ethnographic study of mobile mixed reality game provides one illustration of a hybrid ecology and reflections on the study elaborate articulation work, fragmented interaction, and seamful representation as core topics informing wider investigation of emerging physical-digital environments. Fundamentally, understanding cooperative interaction in hybrid ecologies requires us to unpack the fragmented character of interaction, which will consist of uncovering the ordinary interactional competences that users exploit to make differentially distributed mechanisms of interaction work and the distributed practices that articulate seamful representations and provide for awareness and coordination.

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