From Interaction to Participation: Configuring Space Through Embodied Interaction

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Abstract. When computation moves off the desktop, how will it transform the new spaces that it comes to occupy? How will people encounter and understand these spaces, and how will they interact with each other through the augmented capabilities of such spaces? We have been exploring these questions through a prototype system in which augmented objects are used to control a complex audio 'soundscape.' The system involves a range of objects distributed through a space, supporting simultaneous use by many participants. We have deployed this system at a number of settings in which groups of people have explored it collaboratively. Our initial explorations of the use of this system reveal a number of important considerations for how we design for the interrelationships between people, objects, and spaces.

1 Introduction

One common characterization of ubiquitous computing is that it engenders a move "off the desktop," implying the migration of information processing beyond traditional computational settings in desktop PCs and into the broader environment. In our work, we have been considering this transition, but from another perspective. Instead of thinking about ubiquitous computing in contrast to the desktop it leaves behind, our main focus is on the space into which computation will move. What sorts of impacts on space result when it is populated by ubicomp technologies?

The topic of augmented environments is one that has occupied ubicomp researchers for some time [3, 23, 30]. In general, these approaches have considered specific spaces and the ways in which they can be made responsive to aspects of human activity. However, our concern here is more generally with the ways in which social action is embodied, and embedded, in space. Our fundamental concern is with the ways in which we encounter space not simply as a container for our actions, but as a setting within which we act. The embodied nature of activity is an issue for a range of technologies. For example, researchers investigating interaction through video-

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conferencing technologies have noted that gesture loses much or all of its effectiveness across video connections, because in the everyday world, gesture happens not on a two-dimensional plane (such as a video screen) but rather in a three dimensional space [16]. Gestures unfold in a space around and between the bodies of communicative partners, and this mutual relationship between bodies, gestures, and space is intrinsic to how gestures work. Similarly, the ways in which spaces can be explored depends on our presence within it and the fact that we are not merely observers but participants in a spatial environment [10, 11].

Space and social action, then, are tightly entwined. The spatial organization of activities makes them intelligible to others; for example, people's mutual orientation in conversation [22], as they walk down the street [26], or as they stand in line [8], provides others with the means to see and interpret what is going on. In other words, this relationship goes beyond simply space and action; rather, it speaks to, first, the mutual configuration and arrangements of bodies, artifacts and activities in space, and, second, the social and cultural practices by which actions are both produced and interpreted. Objects and activities take their meaning from the ways in which they are embedded into systems of practice; through these practices, people configure space for each other and render particular objects and activities "seeable" [12, 13, 18].

This complex relationship is the basis of our inquiry. In particular, we are interested in the ways in which the migration of computation into the everyday environment might reconfigure the relationship between people, objects and space; first, by making spaces responsive to activities in ways not previously possible, and second, by presenting new challenges for the interpretation of actions and objects in space. In other words, how will people be able to make sense of computationally enhanced spaces, and how will they be able to make sense of each other in those spaces?

We have been exploring these questions through the development and evaluation of a collective dynamic audio installation called SignalPlay. In this system, a series of physical objects with embedded computational properties collectively control a dynamic "sound-scape" which responds to the orientation, configuration, and movement of the component objects [21]. The system and its component objects – chess pieces, building blocks, bongo drums, an antique compass, and a toy light saber – are large enough that they cannot all be used by a single person at once; spread through a space, they create a sonic environment which is experienced and transformed collectively by multiple people. SignalPlay has been exhibited a number of times, generally in gallery spaces, and we have observed people's interactions with and through the system. In this paper, we will explore some of our early experiences with SignalPlay, and set out an initial framework for describing and understanding people's encounters with augmented objects and augmented spaces.

We will begin by discussing some current work that explores similar technological and design concerns and which examines the collective configuration of space, particularly in gallery settings. After a brief presentation of the design of SignalPlay, we will discuss our observations of its use and the framework for interaction that is emerging from our analysis. Finally, we will discuss some of our further investigations and the potential implications of this work.

2 Related Work

Our investigations were informed by several areas of previous work, including uses of complex audience spaces as a focus for embodied interaction, use of representational objects in tangible interaction, studies of the collective experience of exhibits and gallery spaces, and considerations of how people come to understand a space that they inhabit.

2.1 Tangible Interaction with Sound

Art practice has long explored ideas of computational sensory feedback based on physical interaction. These ideas appear in 1950's and 1960's explorations such as a photoelectric and microphone controlled sound system designed by Billy Klüver for a series of performances held in October 1966 under the title *Nine Evenings: Theatre and Engineering* [4]. Installation and performance artists such as Myron Krueger and David Rokeby have continued to explore the use of sensor technologies with real-time sound generation. Our use of chess pieces as an interface device evokes a 1968 game of chess played by John Cage and Marcel Duchamp in which the movement of pieces controlled a composition of light and sound.

Work on the use of gestural user interfaces for electronic instruments includes that of the Hyperinstruments group at MIT Media Lab. The *Beatbug* system [34] in particular focuses on users' ability to manipulate musical system behavior at different levels of collaboration and complexity using simple toy-like objects. In contrast, SignalPlay uses music as a means of exploring a novel interface; we do not think of it purely as a musical instrument, but as an experience. It draws on the idea of tangible bits [20] and phicons [32] for the physical design of the objects. Unlike the metaDESK phicons, however, SignalPlay's objects can be thought of not only as non-representational icons that stand in for a digital interaction possibility, but also, and more noticeably, they are more literal icons (and in some cases what Ullmer and Ishii refer to as "actualities") that represent real-world objects with known interactional rules.

In this sense, SignalPlay bears some resemblance to *ensemble* [2], in which common wardrobe items are augmented to turn the childhood game of dress-up into a music manipulation activity. As well, the Cardboard Box Garden [7] uses physically embodied audio spaces to investigate the augmentation of familiar objects with computational capabilities.

2.2 Gallery Studies

Partly because SignalPlay was deployed in a gallery space, it is in many ways related to the *Ghost Ship* installation described by Hindmarsh et al. [19]. In the *Ghost Ship* exhibit, interactive components were distributed throughout a gallery space such that visitors could interact knowingly with a component in their immediate proximity; but sometimes unbeknownst to them, they might also influence other components in the exhibit. Our system is heavily audio-based, while theirs used video images, yet both installations elicited strikingly similar expressions of confusion, surprise and playfulness. These detailed studies of interaction and collaboration in a public place, using close video analysis, informed our methods of observation.

The Ghost Ship study is one of a number of detailed studies of interaction in gallery and exhibit spaces conducted by researchers at Kings College London [17, 33]. A central feature of these studies is that they turn their attention away from HCI's traditional focus on how a single individual might interact with an exhibit, and focus instead on how a group of gallery-goers might interact around a particular object or exhibit. The issue here is not simply that most people visit gallery and exhibit spaces in groups, although this is true [14]. Rather, drawing on a range of studies into the role of objects in the collective production of orderly action, they focus on the ways in which people's actions essentially "configure" the space for each other. People encounter spaces as ones that are populated with others, and exhibits as visible sites of other's activity. Detailed studies of video records show the ways in which people attend to each other's interactions with exhibits, which in turn shape aspects of their own encounters with them. Encounters with exhibits are collective experiences, and individual actions around them are organized with regard to the presence, orientation, activities, and gaze of others. The Kings College group has used these observations in support of design activities [17].

2.3 Understanding Space

In an evaluation of the Sotto Voce system [1] it is noted that mutual eavesdropping through the system, and consequent lack of sound attenuation with distance, could affect couples' spatial interaction with each other. However, the role of sound in shaping understandings of space is not extensively addressed in the ubiquitous computing literature. Anthropology and urban studies have addressed the topic as it relates to spaces on the scale of cities. Dourish and Bell [6] discuss space as infrastructure, shaping and shaped by peoples actions in it and beliefs about it. They present an example of auditory organization of space: children in the British Commonwealth memorize the sounds of London's churchbells through a nursery rhyme, and aural map of the city. Indeed, most European cities of the early modern era generated informative ambient soundscapes, conveying not only neighborhood, but time, significant events and power structures, and encouraging or forbidding certain actions [9]. The aural "landscape" is one of the ways in which the city takes on a shape; similarly, patterns of movement, religious activity, historical patterns of migration and habitation, etc, all serve to shape landscapes and make them collectively intelligible [27]. Dourish and Bell argue that ubiquitous computing technologies and the infrastructures upon which they depend similarly offer an infrastructure through which space can be encountered and understood.

In his discussion of context-aware technologies, Svanaes [29] notes that space "comes into being through interaction" and discusses simple technological probes aimed at highlighting how people come to understand augmented space. It may be informative to think of SignalPlay as just such a probe.

3 System Design and Implementation

We take two lessons from these studies. First, at a broad level, they demonstrate the complexity of the relationship between technologies and spatial encounters. Interactive technologies are encountered not simply in their own right, but also as elements in spaces populated by other technologies and people, and which is a site of social action and social meaning. Second, that, although gallery spaces are outside the primary traditional domains of ubiquitous computing application, the exploration and creative engagement that they encourage can provide us with a site for exploring these questions.

Our goal, then, was to create a system that we could use as an experimental testbed for understanding how people explore and understand ubicomp technologies as spatially situated phenomena. The primary criteria were that, first, that the system should be distributed in space; second, that it should allow for simultaneous use by multiple individuals acting independently or in concert; and third, that it slowly disclose its operation. Our prototype system, SignalPlay, addresses these goals by using augmented objects as collective controls for a complex audio space. Deployed in gallery settings, it allows us to explore the ways in which people individually and collectively explore the intersection between spatiality and activity.

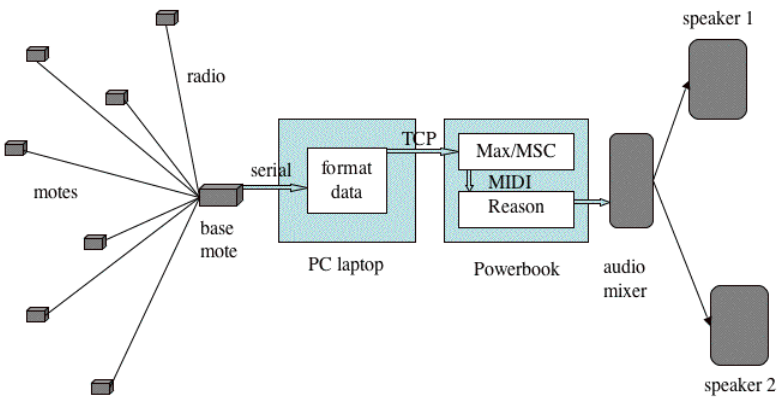

Figure 1: System Diagram of SignalPlay

3.1 Infrastructure

SignalPlay was implemented using Crossbow Mica2 motes running TinyOS. These 1-3/4" x 2-1/2" devices are small enough to be embedded into toys, and are capable of forming ad-hoc networks via radio. The motes were fitted with sensor boards that included accelerometers, magnetometers, light sensors, thermistors, and microphones.

The sensor data from each mote was transmitted at regular intervals of 50, 100 or 200 milliseconds, depending on the reaction time required, to a receiver mote, which was attached by serial connection to a PC laptop. A Java application read and formatted the sensor data and sent it via TCP/IP to a Macintosh laptop, which parsed the sensor data and generated the audio content based on changes caused by user manipulation of the object. The object behaviors and music content were programmed in Max/MSP and Reason. These two programs communicated with each other via MIDI, and the spatialized audio was output through a multi-channel sound interface.

3.2 Interface Objects

We designed or selected specific objects based on their capacity to elicit certain behaviors and on their relation to the theme of "play." On the one hand, the objects must, through their physical affordances, suggest how they should be handled; on the other hand, their effect upon a complex audio environment is difficult to convey through form alone.

The objects were three giant chess pieces (a rook and two pawns), five oversized building blocks, two bongo drums, a navigational compass in a wooden box, and a Star Wars lightsaber.

The three chess pieces sat on the ground amid a "chess board" of six disjoint squares, designed to cue the participant to move the pieces around the space, but with gaps and shifts in the grid arrangement to indicate that rule-based chess was not required. Each piece was about two feet high. A mote was placed inside each chess piece such that moving and setting down the chess piece triggered its behavior.

Five 12" cube building blocks were arranged on and around several small pedestals. Each had a hole in the top under which a light sensor is placed. The expected behavior of stacking blocks on top of one another dropped the light reading below a set threshold and the system responded to that stimulus.

The bongos had holes in the top, at the center of the drumming surface, with light sensors inside each drum. In striking the center of the drums the user could affect the light readings and thereby controls a bass line in the system. The system behavior was sensitive to which drum was struck and how long the light source was obscured. Our augmentations did not greatly affect the sound of simply drumming on the bongos.

The box-mounted compass was hinged in two directions, allowing it to swivel when tilted. A mote was attached to the outside of the box and readings from the attached accelerometer and magnetometer were used to control sound. When the compass was at rest or the compass lid closed it was silent. By opening the lid, the user activated its sound and controlled various parameters of a waveform synthesizer by moving, tilting and rotating the compass.

The lightsaber was an off-the-shelf plastic Star Wars lightsaber fitted with a mote mounted to the handle. It sounded upon sensing motion and was silenced after several seconds at rest. When swung by a participant, the speed at which it moved dictated the enacting of sampled sounds.

SignalPlay was deployed first at the opening event for a new research building at the UCI campus, and subsequently in a gallery space for several days. The installation, both at the building opening and in the gallery space, was arranged such that the chess set occupied territory – indicated by the squares placed on the floor – that was roughly central to the piece. Blocks were placed as a group to one side. The bongos, compass, and lightsaber were placed on two small pedestals to the other side. During the gallery showings the room, approximately 15’x18’, was shared with another installation. The two installations were spatially distinguishable, but not separated; a set of three interactive sculptures was mounted on the wall while SignalPlay was placed on the floor and other horizontal surfaces.

There are several salient features of the design of the objects and the space that we wish to highlight here. First, the actions initially elicited by SignalPlay’s objects do produce discernable effects on the system, but other effects can be gradually revealed through use over time. Second, the size and design of each object makes it difficult to operate more than one object at a time, making collaboration necessary to reveal all behaviors of the system. And third, the spatial distribution of the objects throughout a single room provided enough space for participants to play individually, but also allowed enough visual and auditory awareness to coordinate with others.

Figure 2: (a) Antique compass with attached mote. (b) A participant poses with the lightsaber. To the left is one of the chess pieces. Behind and to the right are the bongos. (c) Another participant stacks blocks.

3.3 Sound Controls

Each interface object affects the system in a readily apparent way through discrete sound events (*direct controls)* that occur in immediate response to participant interaction. In addition, most of the objects have effects on a system-wide level (*systemic controls*), thereby changing the ways in which the sounds of other objects are processed. Through this second mode of feedback, participants begin to engage in a process of interaction not just between themselves and the system, but also indirectly (and directly through social behavior) with other participants. Participants may thus play with the system individually, affect the response of other people’s instruments, or play in concert.

The systemic control of sound feedback is currently based on control of tonal harmony (keys, scales and intervals), tempo, and timbre. For all of the objects except the lightsaber, we base the direct sounds on a globally specified pitch we call the *tonal center*; if the tonal center is changed, their sounds are transposed in pitch by the same interval. These objects, except for the compass, are also governed by a *scale* of specified intervals relative to that tonal center. The object sounds base their tonal harmony on a *set* of pitches defined by the tonal center and scale intervals. However, object sounds are not confined only to pitches within that set, but can also deviate by a chosen interval from specific pitches within the set.

Most of the directly controlled sounds have an associated tempo, be it the rate at which samples and notes are triggered, the delay and decay times of signal processing modules, or the enacting of dependent processes. Interaction with certain objects causes system-wide tempo changes that affect these parameters. For instance, a transient "hit" on the bongos will trigger that instrument's sound while instead holding your hand continuously over the light sensor will cause the tempo to speed up or slow down (depending on which drum you trigger).

The object behaviors form a continuum from simple and direct control to complex and systemic control in the following order: lightsaber, compass, bongos, chess pieces, and blocks. The lightsaber uses only direct controls with no affect on a system-wide level. This allows its behavior to be very easily understood. The compass is affected by the tonal center but not the pitch sets. The rest of the objects have direct controls with an increasing level of system controls. In addition, there are sounds that are not related to the physical objects; these are based entirely on systemic changes and have no direct control.

4 Exploring and Interpreting Space

We deployed SignalPlay in four showings. The first was the building opening noted above; the other three were showings at the Arts, Culture and Technology building at UCI. During the building opening and two of the gallery showings, we video-recorded people's interactions with the exhibit and received informal feedback from them during and after their interactions with SignalPlay. The video was a mix of handheld, manual recording, allowing close-ups of participant interaction with the system, and stationary video taken at a vantage point from which the entire installation could be viewed. The observations presented here are the results of an initial analysis of these video materials.

As is clear from the earlier description, SignalPlay is both inherently collaborative (since it is physically too large for a single person to explore) and responsive to transformations in its physical configuration; our goal, then, was to use it as a basis for understanding aspects of the interactions between people, actions, and artifacts in augmented spaces. One starting point for this analysis is Ullmer and Ishii's [32] MCRpd interaction model for representational tangible interfaces. Based on the model-view-controller approach to graphical user interface development, MCRpd presents a framework for tangible interaction in which the "view" component is distributed between the digital and the physical. A physical controller cum physical representation affects a digital model, which may output a digital representation.

They point to audio from a speaker as an example of digital representation, and chess pieces and chess boards as examples of physical representations.

We distinguish between two aspects of people's experience in forming an understanding of SignalPlay. The first is learning to *control* the system through the objects; they second is learning to "read" or *interpret* the sound output of the whole system as being a result of purposive human action. These two attributes are analytically distinguishable, as suggested by the MCRpd model, but not separable in practice. We interpret participants' perceptions of SignalPlay to be inextricably bound with their actions within it [25]. Control and interpretation are tied to participants' interactions with each other and with the space they inhabit. As we have illustrated above, people encounter ubiquitous computing technologies in socially-organized settings. Even when they are alone, they act nonetheless in spaces that have social and cultural meanings and interpretations. These factors – not just how people encountered the system along with others, but also how they encountered it in terms of sedimented understandings and metaphors – were significant aspects of our observations.

In what follows, we will discuss some of the experiences of SignalPlay drawn from the video materials. We organize these into three related topics. First, we consider individual interactions with the devices, and how both the material and metaphorical aspects of the artifacts shapes interaction. Second, we move from an individual to a collective level, discussing how people used aspects of the system to play not simply with the technology but also with each other. Finally, we approach the question of "reading the space" and discuss the ways in which learned how to interpret the actions of the system as the outcome of the embodied practices of actors.

4.1 Modes of Object Interaction

Our first consideration is the ways in which individuals encountered the system, and how the properties of the artifacts out of which it was constructed – both material properties and metaphorical properties – shaped and constrained their interactions.

Objects were designed to evoke certain behaviors by resembling everyday artifacts; however we also wanted to invite exploration by making it evident that these objects were augmented. Physical cues indicated that the objects were not exactly what they represented: the chess set was incomplete, the chess board strewn across the floor in a not-quite-grid, and the motes' antennae poked out of the blocks. As participants learned to exploit the digital augmentation of SignalPlay's toys, their engagements with the objects varied, reflecting different forms of engagement both with the objects themselves and with the effects that they controlled. We observed three major categories of use: iconic, intrinsic, and instrumental.

Iconic interaction entails interacting with a physical icon in the ways afforded by the object it represents. Examples of iconic interaction with objects in SignalPlay include moving chess pieces from one square to another, stacking the blocks, beating on the bongos, or holding the compass in front of oneself while walking around the room. For example, a few participants, while playing with the chess pieces, limited themselves to legal moves, never moving the rook diagonally or the pawns more than one square over. Iconic use, then, is shaped primarily by the metaphors suggested by the physical objects themselves; they are appropriated as augmented versions of their traditional analogs.

Intrinsic interaction takes advantage of the intrinsic physical characteristics of an object. For example, because our chess pieces were hollow, a pair of participants (playing together) proceeded to stack them on top of one another. This mode of play had nothing to do with the object's status as a physical icon of a chess piece, but rather responded to the physical configurations of the objects themselves. Turkle and Papert [31] report a wonderful illustration of intrinsic interaction in their dicussion of *bricolage* among elementary school students learning engineering concepts. Given an assignment to propel a small robot forward using a motor, many of the children used the motors to drive wheels; one boy, however, used a motor to drive a robot around directly by the force of its vibration. He did not think of the tool as an instance of the category *motor*, but rather as a thing that vibrates in such a way that might move a small robot around. Similarly, the idea to tilt our compass does not come from its "compassness", but rather from the fact that it happens to swivel in an interesting way when tilted.

Figure 3: Stackable chess pieces

In comparison to the two earlier modes of interaction, instrumental interaction is not focused on the physical objects themselves, but on the effects that they engender; people engaged in instrumental interaction reach "through" the objects, focused on using them as controllers of a digital system. In the case of SignalPlay, users took advantage of the ways in which the musical sounds were influenced by manipulation of the object, treating it similarly to a musical instrument. For example, we observed a participant "playing the compass" by a combination of tilting, swiveling his wrist, and closing and opening the lid. A pair of women played with the blocks by a combination of stacking and covering light holes with their hands or other objects. Instrumental interaction may exploit the intrinsic physical features of the augmented object, (as in covering light holes) or it may be externally the same as the iconic interaction (as in stacking the blocks), or it may constitute a combination of the two; the critical aspect of instrumental interaction is the user's understanding of the object and system.

Our observations of participants' play revealed in each object a different interrelation between these three modes of interaction. For example, the lightsaber had been augmented simply to make the sounds that might be associated with it through the Star Wars films; it did not affect any other sounds in the system. In this case, instrumental interaction did not differ significantly from iconic interaction; it acted just as a lightsaber is "supposed" (or might be expected) to act. In contrast, iconic interaction with the compass, triggered only a subset of the possible sounds. The intrinsic interaction of tilting the box allowed participants greater control over the pitch of the compass's sound. Participants generally understood the lightsaber right away, and we observed numerous instances where a participant might pick it up, play for just a few seconds, and quickly put it down or try to hand it off to another person. In the case of the augmented compass, we found many instances of extended interaction over several minutes, frustration, exploration, discovery and failure.

Figure 4: "Playing the compass" by tilting, closing and opening.

Initial Conditions and Sequential Experience. Participants' interaction with SignalPlay proceeded in an approximate sequence. A tentative poke may lead to engaged iconic interaction. Further exploration may involve intrinsic interaction, then confident use of the object as instrument. Instrumental interaction may then lead a participant to exploit more of the object's intrinsic characteristics. This sequence describes only a general trend. Participants' behavior could be influenced by their initial experience, which helped determine *which* exploratory actions they tried.

A man who tried raising and lowering the compass had some success affecting pitch change in that manner. When he subsequently played with the bongos, failing to make them trigger a sound by drumming them, he then tried to raise and lower them as he had with the compass. This action is not particularly afforded by the bongos, either physically or instrumentally.

We logged numerous instances of participants playing while a friend watched, sometimes right at their shoulder, pointing and suggesting actions. As the crowd grew, we logged an increasing number of participants watching and being watched by strangers who simply stood back and did not interact with the person at play. Mutual watching informed participants' understanding of how to control the system through objects; as watching increased, participants tended to become less tentative and more engaged. Some participants, after watching for some time, skipped iconic interaction altogether, imitating a more experienced participant's instrumental interaction.

Space and Modes of Interaction. In the case of the compass, when people thought of it iconically, they tended to cover more space, walking about the room holding the compass. When they started thinking of it more instrumentally, they were more likely to play it standing stationary and changing only direction and tilt. We saw this transformation take place in the case of one man who was bent on understanding the compass; though he roamed the room at first, after five minutes playing with it he was controlling the sound confidently and with his feet planted in one spot.

Playing with the blocks or the chess pieces as a collocated set reinforced the iconic nature of the objects. This became evident during one of the gallery showings when two participants moved the blocks and bongos onto the chess board into the middle of the room, disrupting the objects' clearly demarcated territories. Their treatment of the objects changed drastically as a result of this move. One covered the light hole on the bongo with one hand, swinging the lightsaber with the other and using it to cover a light hole on one of the blocks. Meanwhile her friend, as she bent to set it down a chess piece with one arm, covered the second light hole on the bongos with her other hand. Other participants followed their lead and adhered far less to iconic interaction than previously. That this disruption of the exhibit's spatial setup had such a noticeable effect on participants' object interactions indicates that their understanding of the system is affected not a little by how they think of it within the space of the gallery.

4.2 Collective Encounters and Interpretation

People tended to encounter SignalPlay in groups. One interesting set of issues, then, concern the ways in which it mediated collective experiences. People respond both the technology and to the setting within which it is encountered – in our cases, a technological demonstration or a gallery space. These settings lend meaning to the technology, as something to be explored and understood, but not necessarily to be used as a tool. These contexts shape and limit forms of engagement; the socially understood settings both "script" people's encounters with the technology (time-limited, to be shared with others, not to be taken away, etc) as well as making the space and the technology "legible" (in terms of, for example, how the various elements of our system could be seen as part of a single "piece" but distinguishable from others nearby.)

Playing with Others. Like Hindmarsh et al's *Ghost Ship*, the interactional capabilities of SignalPlay manifested themselves fully when the gallery space was crowded. Crowds lent themselves to group play and observation of participants by other participants, both of which encouraged instrumental interaction.

The chess set is a case in point. Due to the size and dispersal of the chess pieces, one person could not move them rapidly enough to make the tonal change obvious. At one showing, once the workings of the system were explained to the participants, two pairs of women gravitated towards the chess set, which had previously generated interest only in a couple individuals. These two groups remained engaged for longer than the previous solo players and, in attending to the objects' capacity as sound controllers, departed more from the iconic cues of the chess pieces; illegal moves were made more readily and conventions of turn-taking were discarded. One pair was quite aware of their departure from iconic interaction, commenting that "no one can win this game!" and cracking jokes about how they should have a chess timer

In later gallery showings that lasted longer and drew larger crowds, participants would roll a chess piece around the edge of its base, or hold it up and swing it, triggering chord changes in quicker succession than they would have if making chess moves. Indeed, it was during games of "speed chess", and other interactions that triggered rapid change, that the effect of the rook on the tonal center of the system became evident. Those of us who do not have perfect pitch depend on our imperfect memory in order to hear intervals. A single person engaging in iconic interaction with the objects in SignalPlay, then, typically does not reveal the systemic sound effects of some of the objects because of this temporal aspect of the system. On Hindmarsh's *Ghost Ship*, space was the key element in understanding the exhibit, since video images taken in one part of the room were displayed to other people in another part of the room. This was true for SignalPlay, since moving the rook in one part of the room would affect the tonal center for other objects scattered about the space, however time was also a critical factor. In SignalPlay, systemic sound controls were most evident when several users interacted at the same time, triggering objects in quick succession.

Peripheral Awareness and Mutual Monitoring. Unsurprisingly, participants' attention might be drawn to one another due to loud talking or sudden motions. Co-presence and peripheral awareness of companions' locations proved to be a crucial component in visitors' understanding of *Ghost Ship* [19]. In SignalPlay as well, awareness of people in space was a necessary step towards an understanding of system sound in space. However, participants' awareness of each other in the *Ghost Ship* installation was based on vision more exclusively than in SignalPlay, where awareness of others' actions did not necessarily depend on the direction of ones' gaze.

Participants frequently monitored each other through the system. For instance, a girl playing with the blocks demonstrated awareness of her friend playing with the compass, turning towards the camera, widening her eyes and smiling when the compass sound suddenly changes in quality. Additionally, participants are aware of each others' awareness, and explorations took on a certain aspect of performance. Two girls playing with the blocks dance to the music, and people playing with the lightsaber adopt dramatic poses.

This mutual monitoring through audio was not deliberately designed into the system, but rather the result of simple, but public interaction. Grinter et al [14] noted a similar phenomenon in the Sotto Voce system: the system was meant to allow pairs of museum visitors to share audio content regarding the exhibits, but it was used in addition to monitor the location of companions. In this case the information shared is not so explicit, but it is shared more widely, to strangers and friends alike.

4.3 Reading the Space

Finally, here, the experiences with SignalPlay also highlight our concern with the ways in which actions in space become readable and interpretable to others. We encounter spaces as particular kinds of places [15]; as public or private, as spaces of work or leisure, as rowdy or dignified, etc. In our deployments, we were particularly interested in the “legibility” of space and technology – that is, in how people could learn to read it or interpret it, and in particular how they could read the system’s activity as being a consequence of their own and others’ actions.

A direct physical mapping between the gallery space and SignalPlay’s audio output would identify the sounds as coming from the speakers, located in certain corners of the room. On only one occasion, however, did a participant actually indicate the speakers as the source of the sound, an 8-year-old boy who wanted to know how we got the sounds from “there” (the bongos) to “there” (pointing at speakers). Though he knew intellectually where the source of the sounds were physically located, interactionally he mapped the sounds to the space quite differently. Seconds after he pointed out the speakers, the rook was moved, triggering the associated sound. Looking up from the bongos, he pointed towards the chess set. In this section, we examine how our participants might come to understand SignalPlay’s audio output in space as something more than a simple physical correspondence. Participants’ interpretation of the SignalPlay space was built upon their awareness of people in space, as previously discussed, as well as a strong association between sounds and objects, objects and territory, and awareness of each other’s sound-producing actions.

Transferring Focus to Objects. We saw numerous instances of participants examining motes that were attached externally to the lightsaber and compass. However, we also saw a man peer inside the compass box, despite the visible mote. We also noted a woman who put the compass up to her ear, as if expecting the sound to emanate directly from it. These were the most noticeable illustrations of the general tendency to focus on the physical objects as the source of the sounds and regard the digital system as transparent. Universally, when a participant’s attention was attracted by a sound associated with a certain object, they turned not towards the physical source of the sound – the speakers – but to the causal source of the sound, the object.

Physical Objects Demarcate Space. At one point during one of the gallery showings, a participant separated one of the blocks from the set, placed it on the floor next to one of the sculptures from the other installation sharing the room, and ran an Ethernet cable from that sculpture into the hole on top of the block that allowed light to reach the light sensor inside. This breached the grouping of the blocks, expressed by keeping them all in the same territory, not to mention the spatial distinction between the two installations. The displacement of that block proved to be an exception that proved the rule; it drew looks, comments, and jokes from other participants.

Different objects elicited different spatial behaviors. The lightsaber, compass and bongos tended to “wander” but return home. A participant might roam around the room with the lightsaber, poking their friends and swinging it around. Participants commonly walked around with the compass, and in fact that movement can be considered an example of iconic interaction encouraged by the compass. However, participants almost always put them back exactly where they found them.

The chess pieces on the other hand, were placed on a chess board, a clearly demarcated piece of territory. Though they were moved around, they were rarely moved off of the chess board. The blocks, for the most part, stayed on the pedestals on which they were originally placed. Territory was not marked for the blocks, any more than it was for the compass, which traveled more. The key difference was that while the iconic interaction with the compass required movement through space, the blocks encouraged stacking in place. Thus the interactional properties of the objects affected how participants fit them into the space of the exhibit.

Sounds and Sound-Producing Action. Sounds in SignalPlay are caused by visible action, allowing watchers to associate a sound with an object and the person controlling it, and thereby making the system's audio output interpretable. During a gallery session, three women off camera are discussing "the bong" and in order to clarify its source to them another participant simply picks up the rook and moves it. This demonstration makes explicit a usually implicit process of monitoring other participants' actions and associating them with system sounds.

These three aspects of interaction – with the artifacts themselves, with others, and as a means of reading space – are not separate behaviors; they arise in concert with each other. Here they provide us with a starting point for understanding the relationships between people and activities in augmented spaces, and how ubicomp technologies transform the legibility of actions in space. Although gallery settings differ from office, domestic, or mobile settings in which ubicomp technologies may be deployed, those settings are also populated by people and by technologies, and ones that must be interpreted and transformed through practical engagement. Our data illustrate that the collective, spatial, and sequential aspects of encounters with ubicomp environments are critical factors in how those technologies will be put to collective use.

5 Conclusions and Implications

Our world is both physical and social. While we might distinguish between these as analytic concerns, they are fundamentally intertwined as practical matters. Just as it is impossible for us to encounter space independently of its physical characteristics, it is equally impossible for us to encounter it independently of its social character and organization. This social character means that spaces are not "given"; they are the products of active processes of interpretation. The meaningfulness of space is a consequence of our encounters with it. For ubiquitous computing, this is an important consideration. We are engaged in the development of technologies that are rapidly moving out of traditional computational settings – laboratories and workplaces – and into everyday environments. Ubiquitous computing research is actively concerned with domestic environments, with technology in leisure settings, with mobile technologies, and with a range of computational embeddings in space. The research challenge, then, is to understand how it is that computationally augmented spaces will be legible; with how people will be able to understand them and act within them.

Taking this perspective highlights some aspects that are traditionally hidden in the ways in which we think about ubiquitous computing and interaction. Our traditional focus, drawn from decades of research on HCI, is on how people might interact with technologies. However, as we can see from observations with SignalPlay, this is a narrow perspective. Instead, we have been looking at how people engage with space and with each other through the technologies that we provided to them. Rather than focusing on interaction, we focus on participation; how people collectively act in space, and through that participation, achieve concerted social action.

Our SignalPlay deployments scarcely scratch the surface of this topic. They were limited in both scope and duration, and so provide only a brief snapshot of the ways in which people engage with augmented spaces. Nonetheless, the experiences are telling. A number of broad observations are particularly notable.

First, it was notable that people sought to understand the system not as a whole but in terms of the individual actions of different components. That is, although the different physical objects in SignalPlay embodied different controls and inputs for a single distributed system, people interacted with the system instead as a series of individual elements. In cases where, as we described, people essentially focused on the objects themselves as sound-producing (rather than sound-controlling), this was particularly clear. We are used to interacting in a world of non-communicating objects, with individuable characters and natures. This remains a primary element of people's encounters with these technologies. Objects take on meanings and interpretations in their own right rather than as elements of a "system." This suggests, then, that user's experiences and interpretations of ubiquitous computing systems will often be of a quite different sort than those of their designers, because of the radically different ways in which they encounter these systems. Narratives or design models based around a "systems" model should be tempered by alternatives constructed in terms of individual objects with unique identities, histories, and properties.

Second, one particularly interesting area for further exploration is the temporal organization of activity. In previous explorations of technologically augmented spaces, the primary focus has been on how computational power could transform the structure of those spaces for interaction, collaboration, or communication. For example, using video technologies to "link" spaces produces a "warping" of space for communication. However, our experiences with SignalPlay drew our attention to the ways in which information technology can transform the temporal structure of space and interaction. We currently lack good design approaches for understanding the temporal aspects of technologies; not just the sequential organization of interaction, but aspects of pace and rhythm. The temporality of interaction and encounters with technology is a neglected aspect of interaction design and an important part of our ongoing work.

Lastly, ubiquitous computing technologies are ones through which people encounter and come to understand infrastructures. As Star [28] notes, infrastructure is "sunk into" other technological systems and systems of practice. Mainwaring et al [24] have noted that infrastructure may itself be a site for negotiating social roles or for marking social categories, but our concern here is more the ways in which infrastructure manifests itself as an aspect of experience. The presence or absence of infrastructure, or differences in its availability, becomes one of the ways in which spaces are understood and navigated. At conferences or in airports, the seats next to power outlets are in high demand, and in a wide range of settings, the strength of a cellular telephone signal becomes an important aspect of how space is assessed and used. As we develop new technologies that rely on physical but invisible infrastructures, we create new ways of understanding the structure of space [29]. Again, this departs from the ways in which we normally think and talk about ubiquitous computing systems as designers, where our focus is primarily on the technologies and less on the spaces that those technologies occupy. Our design models must address space not as a passive container of objects and actions, but as something that is explicitly constructed, managed, and negotiated in the course of interaction; and at the same time, we need to be conscious of ways in which new infrastructures provide new ways of encountering space.

SignalPlay is an initial examination of people's interactions with and through computationally augmented objects and spaces. Our focus is less on technical innovation and more on uncovering behaviors and understandings that will inform future work. This includes augmenting a new interdisciplinary research building with a sensor network infrastructure that will support ambient displays of presence and activity, and enhancements to SignalPlay itself, incorporating network topology and radio signal strength in order to tie the system more closely to physical space. More broadly, our research in this area further develops the 'embodied interaction' paradigm, which concerns itself with how technologies and artifacts take on meaning for their users through their embedding into systems of practice [5]. This relationship between people, objects, and activities, cast in terms of the ways in which practice evolves, is a central consideration for future developments in ubiquitous computing.

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References

1 Aoki, P., Grinter, R., Hurst, A., Szymanski, M., Thornton, J. and Woodruff, A.: Sotto Voce: Exploring the Interplay of Conversation and Mobile Audio Spaces. Proc. ACM Conf. Human Factors in Computing Systems CHI (2002), 431-438.
2 Anderson, K.: 'ensemble': Playing with Sensors and Sound. Ext. Abstracts ACM Conf. Human Factors in Computing Systems CHI (2004), 1239-1242.
3 Burrell, J., Gay, G., Kubo, K., and Farina, N.: Context-Aware Computing: A Case Study. Proc. Intl. Conf. Ubiquitous Computing Ubicomp (2002), 1-15,
4 Dinkla, S.: From Participation to Interaction: Toward the Origins of Interactive Art. In: Leeson, L.H. (ed.): Clicking In: Hot Links to a Digital Culture, Bay Press. (1996), 279-290.
5 Dourish, P.: Where the Action Is, MIT Press. (2001)
6 Dourish, P. and Bell, G.: The Experience of Infrastructure and the Infrastructure of Experience: Meaning and Structure in Everyday Encounters with Space. Working paper (under review) (2005).
7 Ferris, K., Bannon, L.: "…a load of ould Boxology!" Proc. Conf. Designing Interactive Systems DIS (2002), 41-49.
8 Garfinkel, H. and Livingston, E.: Phenomenal Field Properties of Order in Formatted Queues and their Neglected Standing in the Current Situation of Inquiry. Visual Studies, 18(1), (2003), 21-28.
9 Garrioch, D.: Sounds of the City: The Soundscape of Early Modern European Towns. Urban History, 30(1), (2003), 5-25.
10 Gaver , W.: The Affordances of Media Spaces for Collaboration. Proc. ACM Conf. Computer-Supported Cooperative Work CSCW (1992).
11 Gaver, W., Smerts, G., and Overbeeke, K.: A Virtual Window on Media Space. Proc. ACM Conf. Human Factors in Computing Systems CHI (1995).
12 Goodwin, C.: Professional Vision. American Anthropologist, 96(1), (1994), 606-633.

13 Goodwin, C.: Seeing in Depth. Social Studies of Science, 25, (2003), 237-74.
14 Grinter, R., Aoki, P., Hurst, A., Szymanski, M., Thornton, J., Woodruff, A.: Revisiting the Visit: Understanding How Technology Can Shape the Museum Visit. Proc. ACM Conf. Computer-Supported Cooperative Work CSCW (2002), 146-155.
15 Harrison, S. and Dourish, P.: Re-Place-ing Space: The Roles of Place and Space in Collaborative Systems. Proc. ACM Conf. Computer-Supported Cooperative Work CSCW (1996).
16 Heath, C., Luff, P.: Disembodied Conduct: Communication Through Video in a Multi-Media Office Environment. In Proc.ACM Conf. Human Factors in Computing Systems CHI (1991) , 99-103.
17 Heath, C., Luff, P., vom Lehn, D., Hindmarsh, J.: Crafting Participation: designing ecologies, configuring experience. Visual Communication, SAGE Publications (2002), 9-33.
18 Hindmarsh, J. and Heath, C. : Sharing the Tools of the Trade: The Interactional Constitution of Workplace Objects. Journal of Contemporary Ethnography, 29(5), (2000), 523-562.
19 Hindmarsh, J., Heath, C., vom Lehn, D., Cleverly, J.: Creating Assemblies: Aboard the *Ghost Ship*. Proc. ACM Conf. Computer-Supported Cooperative Work CSCW (2002), 156-165.
20 Ishii, H., Ullmer, B.: Tangible Bits: Towards Seamless Interfaces Between People, Bits and Atoms. Proc. ACM Conf. Human Factors in Computing Systems CHI (1997), 234-241.
21 Kabisch, E., Williams, A., Dourish, P.: Symbolic Objects in a Networked Gestural Sound Interface. In Ext. Abst. of ACM Conf. Human Factors in Computing Systems CHI (2005).
22 Kendon, A.: Studies in the Behavior of Face-to-Face Interaction. Peter de Ridder Press, Lisse, Netherlands (1977).
23 Koile, K., Tollmar, K., Demirdjian, D., Shrobe, H., and Darrell, T.: Activity Zones for Context-Aware Computing. Proc. Intl. Conf. Ubiquitous Computing Ubicomp (2003), 90-106.
24 Mainwaring, S., Chang, M., and Anderson, K.: Infrastructures and their Discontents: Implications for Ubicomp. Proc. Ubicomp (2004).
25 Robertson, T.: The Public Availability of Actions and Artefacts. In: Computer Supported Cooperative Work, 11, (2002), 299-316.
26 Ryave, A. and Schenkein, J.: Notes on the Art of Walking. In: Turner (ed.), Ethnomethodology, London: Penguin (1974), 265-274.
27 Smail, D.L.: Imaginary Cartographies: Possession and Identity in Late Medieval Marseille. Ithaca: Cornell, (1999).
28 Star, S.L.: The Ethnography of Infrastructure. American Behavioral Scientist, 43(3), (1999), 377-391.
29 Svanaes, D. Context-Aware Technology: A Phenomenological Perspective. Human-Computer Interaction, 16(2-4), (2001), 379-400.
30 Truong, K., Abowd, G., and Brotherton, J.: Who, What, When, Where, How: Design Issues of Capture & Access Applications. Proc. Intl. Conf. Ubiquitous Computing Ubicomp (2001), 209-224.
31 Turkle, S. and Papert, S.: Epistemological Pluralism and the Revaluation of the Concrete. In: I. Harel & S. Papert (eds.): Constructionism. Norwood, NJ (1991), 161-192.
32 Ullmer, B. and Ishii, H.: Emerging Frameworks for Tangible User Interfaces. In: Carroll (ed.): Human-Computer Interaction in the New Millenium, Addison-Wesley, (2001), 579-601.
33 Vom Lehn, D., Heath, C. and Hindmarsh, J.: Exhibiting Interaction: Conduct and Collaboration in Museums and Galleries. Symbolic Interaction, 24(2), (2001), 189-216.
34 Weinberg, G., Aimi, R., and Jennings, K.: The Beatbug Network – A Rhythmic System for Interdependent Group Collaboration. Proc. NIME (2002).