Fostering Human Connectedness: Awareness Over a Distance Using Networked Furniture

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Abstract

The demands of modern working life increasingly call upon people to be separated from their loved ones for prolonged periods of time. Intuition leads us to believe that people have an innate desire to maintain an awareness of the people they care about. The shared awareness between people in tightly bound relationships plays a subtle but essential role in communication.

Communication technology is now so pervasive that the possibility of being apart without being able to stay in touch is almost non-existent. However, many present-day communications technologies cause untimely interruptions, which may lead to unnecessary stress. More importantly, they lack the ability to express the depth and range of emotionality people want and need. These factors exacerbate the symptoms of feeling disconnected from loved ones when away from home.

The aim of this thesis was to develop a system for providing awareness between people in long-distance relationships. An extensive survey of research in the fields of telepresence, media spaces, ubiquitous computing and ambient media was undertaken to gain an understanding of previous approaches related to the problem.

A concept demonstrator was created to investigate new ideas and establish design recommendations for a awareness technology. A rapid prototyping methodology was used to create *Habitat*, a range of networked furniture for providing awareness of daily routines and rhythms over a distance.

The prototype was deployed at numerous events, including research open days and an international exhibition. A great deal of positive feedback was received, validating many of the ideas behind the work. The work developed illustrates significant scope for new approaches in designing communications technology. Further studies are required to establish the effectiveness of the system in real-life situations.

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Contents

List of Figures

Chapter 1

Introduction

1.1 Overview of the Problem

Intuition leads us to believe that people have an innate desire to have an awareness of the people they care about. The shared awareness between people in tightly bound relationships plays a subtle but essential role in communication; it acts as a medium to convey underlying feelings and needs - ensuring that the relationship can survive and flourish.

The ability to perceive the emotional state of others is one of the defining characteristics of humanity, often taken for granted since it comes so naturally. Cohabiting couples rapidly build up an implicit understanding of their partner's moods and daily routines. Knowledge about each partner's activities such as sleeping, eating, going to work or socialising are important for a number of related reasons. At the most basic level, this information helps to foster feelings of reassurance and connectedness between the pair.

Reassurance can come from being aware that the other partner is 'safe and sound'. Knowledge of a partner's regular routines is another factor in providing reassurance as they can be important in determining well-being - major deviations from previously consistent patterns are significant since they can indicate stress or illness. A sense of connectedness can result simply from just being aware that the other person is 'there'. The ability to freely reach out and interact with a partner strengthens the feeling of being closely connected.

People that are closely bonded are generally more aware of their partner, in particular one another's routines and rhythms. Couples may find that their individual rhythms and routines change when they are together as a result of a subtle process of background synchronisation, further strengthening the feeling of connectedness in the relationship.

The reciprocal nature of awareness information flowing back and forth between a couple when they are together could play an essential role in developing intimacy within relationships. The underlying desire for intimacy between a closely bonded couple usually manifests itself as the recurrent need to maintain consciousness of one other. These feelings tend only to intensify during periods of separation.

The demands of modern working life increasingly lead people to be separated from their loved ones for prolonged periods of time. It is obvious that relationships in which there are problems with explicit (verbal) communication between partners, the relationships will usually fail. Implicit (non-verbal) communication in relationships is of equal importance. Today lives are enriched by pervasive technology that conquers distance to such an extent[1] that the anxiety of being apart without being able to stay in touch is almost non-existent. Communication is possible anywhere, any time and any place.

But a practical consequence of today's lifestyles, where many relationships rely heavily on technology-mediated communication to eliminate distance, is that people can still feel disconnected or not attuned with their partner. Few people intentionally choose to pursue long-distance relationships. A reason for this may be that current communications technology satisfies explicit (verbal) communication but does not adequately address the implicit component.

Old-fashioned methods of keeping in-touch such as letter writing are widely accepted as conveying a greater sense of intimacy. Letter writing requires a certain amount of investment in time and attention, therefore is seen as a much more personal medium to both the sender and recipient. The hunger for instant gratification, as provided by the technology of today, is in stark contrast

[1]United Nations Statistics on Global Telephone, Internet and Cellular Subscribers - http://unstats.un.org/unsd/cdbdemo/cdb_source_xrxx.asp?source_code=36

with the slow and deliberate act of writing a letter. Although it is possible to take a great deal of time and thought over an e-mail or text message, the medium itself doesn't exude this quality or enforce such a behaviour.

The majority of modern communications technologies cause untimely interruptions, which may lead to unnecessary stress. They can require a significant amount of effort to learn and use with unnatural interfaces. Most importantly, they lack the ability to express the depth and range of emotionality people want and need. These factors further exacerbate the symptoms of feeling disconnected from loved ones when away from home.

1.2 Scenarios

Three typical scenarios that emphasise the problem of disconnectedness are presented below. These specific instances highlight some of the generic problems that may occur in long-distance relationships and also some of the motivations behind potential remedies to the problem, point to probable application areas, and provide a context for further discussion of the solution.

1.2.1 The Student

Mark recently got accepted on an undergraduate course at an American university. He used to live in Manchester with his mother, Susan. Typical of most teenagers in Europe, Mark was a heavy user of text messaging on his mobile phone for short ad-hoc conversations with his friends throughout the day. Since moving to Boston, the five-hour time difference and cost of international calls has deterred him from keeping his mobile phone.

Mark is able to get online most of the time with his laptop, since his room in halls of residence is connected to the university network and there are many wireless 'hotspots' around campus. Mark uses a combination of e-mail and instant messaging to stay in touch with his friends back home. He finds that instant messenger is not as useful as his mobile used to be, since many of his old friends are not online as regularly as he is. Mark's instant messenger program supports a microphone and web-cam so when he makes the effort to schedule a chat session with his friends they are able to have a rich conversation.

Conversely, since Mark doesn't have a mobile or a telephone in his room, his mother is finding it difficult to maintain contact. Susan works part-time in a supermarket and her shifts vary during the week. Mark and Susan often end up playing 'telephone tag'. When Mark calls, Susan is working so he has to leave a message on the answer machine. By the time his mother calls back, Mark is usually out and she has to leave a message on the shared dormitory phone - which Mark doesn't always receive. Inevitably it becomes frustrating, as often it takes a few days for them to talk to each other.

With Mark being so far away from home, Susan worries a lot about whether he is working hard, eating properly and his general well-being. Mark is enjoying his new found independence at university. Although he is concerned that his mother feels lonely, he sometimes feels that he is constantly being checked up on when she calls. Susan is considering getting a computer so she can e-mail Mark, but suspects that it will not greatly improve their communication.

1.2.2 The Commuter

David and his long-term partner, Tania, live in Ipswich. Tania is an investment banker and faces a stressful commute to London every morning. David until recently had a stressful job as an executive at a telecommunications company. David took voluntary redundancy and his aim is to work as a freelance consultant until he retires in a few years. Although Tania is happy with her career, the strain of the commute adds to an already high-pressure job. They both feel they need a change. The couple are keen hill walkers and spend most weekends in the countryside.

Since David quit his job, they both feel they no longer need to live in Ipswich. They sell up and purchase a large country house in a village near Leeds and a small flat in London. Being near to the Pennines allows them to spend more time in the outdoors. Having a flat in London eliminates Tania's tough daily commute and provides the couple with a convenient base in the city for socialising. The couple previously had not lived apart for any great length of time.

The couple are well informed about new technologies and rely on mobile phones, e-mail and instant messaging to stay in touch. Previously they would send each other quick messages, to remind each other about household errands and co-ordinating their activities. Now that they live apart their pattern and style of communication has changed. David, now working from home, is not used to not having people around him during the day. Tania sometimes feels annoyed by the interruptions from the messages David sends when he is feeling bored or isolated during the day. Tania is not allowed to spend too much of her working hours using company e-mail or phones for personal use. Tania also tends to work later now, since she does not like coming home to the empty flat. The couple call each other most nights and look forward to being together on the weekends.

1.2.3 The Off-Shore Worker

John has been married to Linda for nine years. John and Linda have a six year old daughter, Emily. They live together in Fraserburgh, a small fishing village on the north-east coast of Scotland. Linda stays at home to look after Emily, while John is employed as an offshore technician on a remote oil rig in the North Sea.

John's employers require alternating periods of three months working offshore with three months leave on shore. The environment offshore is physically demanding and stressful. John's employers provide high quality living quarters, plenty of recreation facilities and pay for all living expenses as compensation. John remains in touch with his wife and daughter using the oil rig's satellite telephone link. Since using the satellite telephone is costly, each employee is only allowed to use the system for personal calls once a week. The same system allows for low bandwidth Internet access, but the family don't have a home computer and are not very computer literate.

John finds working offshore a particularly isolating experience since his extended family and friends cannot easily contact him. Naturally, Linda worries about John while he is away because she knows the work can be dangerous. She eagerly waits for his weekly call which is usually at the same time each week to make things more predictable.

1.3 Design Principles

The scenarios described above form a common ground to represent a cross-section of the problems of awareness in long-distance relationships. A number of design predicates can be distilled out of these scenarios, some of which are presented below in order to capture the requirements and defining the characteristics of a potential solution. These principles in essence help simplify and focus efforts in conceiving a solution. As expected, the implications of applying these principles reflect design choices made for the solution presented in this thesis.

1.3.1 Two Places, One Household

In essence, the problem is one of proximity. In the example scenarios, the subjects are not able to be physically together all of the time. The separation is such that it is not easy or convenient to travel the distance involved at regular intervals, so the couples live apart. Although, the distance is primarily a geographic one, a potential side-effect of spatial separation is temporal separation. Living far away can sometimes mean living in a different time-zone. It can be argued that time-zones are merely artificial man-made points of reference created to organise human activity and that one moment of time at one point in the world occurs at the same moment everywhere else in the world. But the fact remains that most people conventionally organise their endeavours around the waking hours of daylight and these patterns of daylight vary across the globe. Couples living in different time-zones may feel disconnected because local points of reference to events during their day, such as lunchtime, differ from one another.

The issue of 'remoteness' has several implications on the solution. Firstly, the users of the solution should ideally be partners that are no longer living together or be based in the same locality or town. For example, two people living in separate apartments in the same housing complex would not be suitable candidates. Secondly, the partners cannot see each other throughout a typical day i.e. they do not go to work in the same office. Thirdly, the users of the solution should be relatively isolated from each other throughout the day for a range of practical commitments such as having to be at work, rather than in constant contact via the telephone, e-mail or other communications media because they both have plenty of free time. Lastly, the couple should be separated for prolonged periods, sufficient time for their absence to be markedly felt. A short overseas business trip for a week would not be sufficient time apart. The ideal solution would merge together the two places into one (virtual) household.

1.3.2 Two People, One Relationship

Another facet of the problem is that it is concerned with interpersonal situations. The nature of these relationships in the scenarios are close, committed, intimate, personal, long term and somewhat private - between parent to child, a husband and wife or cohabiting couple. In general, two people have certain kinds of relationship with only one a significant other. Usually, a child only has one person they call mother, or a husband, one they call wife. Although encounters with strangers, public interactions with groups of friends and formal business relationships are types of interpersonal relationships too, they are not the subject of study in this work because typically they are not exclusive relationships with a single significant other.

The 'interpersonal' aspect to the problem implies that the solution should be deployed in a manner that is 'shared between two' rather than for an individual's personal use. The solution should take into consideration an attempt to maintain the various aspects of the relationships listed above. For instance, intimacy is a crucial part of relationships that develops over time spent together - the solution could try to help maintain this intimacy during times spent apart. As discussed in the overview section of this chapter, the majority of technology rarely meets people's needs for implicit communication.

Intimacy, reassurance and connectedness are often expressed in non-verbal, symbolic and ambiguous ways. For the solution to be useful it should allow the expression of these qualities.

Any well thought-out treatment of technologies dealing with personal relationships must consider privacy and trust issues. People living together can use the physical features of being in their own space to control their privacy from outsiders. A solution that attempts to bridge the distance between two remote places must allow the users to safeguard privacy too.

1.3.3 Two Rhythms, One Awareness

The quality of two people being 'aware' of each other is more than simply just conveying presence information. Information about the routines, patterns and rhythms of a partner's activities could add a further dimension to understanding the state of their well-being and potentially lead to deeper feelings of closeness. The underlying concept is that of being 'aware' of patterns between partners. This affords them the opportunity to synchronise with one another; towards sharing one rhythm. It could also be said that the rhythm of one household is the sum of all the activities and 'comings and goings' of each partner. In the scenarios outlined above it is clear that losing the ability to be aware of loved ones can cause unnecessary stress, worry and discomfort. A solution should therefore permit the users the ability to capture and convey not only presence but their activities too, with a view to understanding longer-term routines and rhythms of these activities.

As previously stated the solution should address non-verbal communication, rather that direct spoken communication. This implies that the kind of information flowing through such a system and its style of presentation should potentially be different to traditional communications systems. The scenarios depicted show that users already have access to established technologies such as telephony. Rather than supplant, the solution should try to support proven means of communication. Explicit conversation is a foreground activity that engages each participant in active listening and comprehension. In contrast, awareness of the implicit messages within relationships is primarily a background activity, conducted with a minimum of direct discourse. Both styles of communication are reciprocal; each participant has the same abilities and rights. The solution should enforce such reciprocity and focus on creating a mechanism for a shared background awareness of activities, routines and rhythms between partners.

1.3.4 Two Interactions, One Interface

A solution that aims to generate reciprocal behaviours from its users implies that the simplest interface possible is one that is the same for all users. The scenarios portray a view where although the latest communications technology is available in abundance, it still requires some effort to use to stay in touch. Therefore, developing a new technology in an already crowded communications space is difficult. The current trend is to make communications devices small, mobile, ubiquitous and general purpose. Cellular telephones are one such example where the ability to make calls, text, e-mail, listen to music and play games is possible almost anywhere. This 'Swiss army knife' approach usually makes the devices not particularly well-suited to any one function and difficult to use. This can mean that people begin to appropriate several different methods to perform one kind of communication. Hence, users in our scenario may be able to use e-mail on their cell phones but they purchase a computer since it is easier to read and send e-mail on a computer. People may also segment the devices or applications they use among the different relationships they have. This is a willing separation on their part, for instance they may have one cell phone for personal use that is not used at work because the person (and the employer) wishes to separate personal life from work life.

The implications for the design of our solution are related to creating a single or common interface to the separate interactions occurring at the two locations. A fixed rather than mobile interface would allow the user to segment personal contact away from the work place. The interactions in personal relations are generally clustered around the home; therefore it may make sense to restrict the interface to the living spaces of the couple. The interface to they system could be specific and appliance-like. This is the opposite to a general purpose communications device. Devices with appliance characteristics have a few key elements. Successful appliances become everyday items, because they are easy to use and their purpose is clear. Also, appliances have a single, consistent purpose that it performs well for a wide variety of functions. Ideally such an interface would be intuitive to use, requiring no special training and not cause significant changes in behaviour or distractions to the user.

1.4 Novel Contribution

This work examines the potential of using everyday furniture as a platform to convey awareness between people involved in long-distance relationships. The capture of information relating to activities that each user may be undertaking is done in an unobtrusive manner using the physical artefacts required for the particular activity. The interaction model employed requires no change in behaviour of the users and no specialist knowledge. Information is visualised in an ambient, background manner to avoid distracting users from their daily tasks whilst maintaining a basic level of awareness. The specific novelty lies in using networked furniture to convey daily routines with a view to becoming aware of the rhythm of each partner's activities.

1.5 Structure of Dissertation

The research presented within this dissertation is an attempt to address the problem of conveying awareness in relationships where the partners are geographically separated for long periods of time.

> **Chapter 1** gives a brief background to the problem and presents a few of the many specific situations where the problem may manifest itself. Naturally, these scenarios also represent the potential application areas where a solution would be particularly apt. The observations noted and abstracted from these scenarios form a foundation for the requirements and principles of an approach to designing a solution.

Chapter 2 presents some of the prior research undertaken that is of importance in the field of technology-mediated relationships and in particular the concept of providing awareness-over-a-distance. Drawing on examples from diverse areas such as social psychology to ubiquitous computing, this section explains some basic concepts involved together with discussion and evaluation of some of the approaches taken. The issues and techniques detailed here inform a strategy for constructing new solutions in this field.

Chapter 3 takes the knowledge and insights gained from the previous chapters as the basis for the design of *Habitat*; a system that uses furniture to provide awareness over a distance for people in long-distance relationships.

Chapter 4 presents an account of the development and subsequent deployments of *Habitat*. Observations of any shortcomings or successes from the initial installation of the system are highlighted for further discussion.

Chapter 5 examines the changes and improvements suggested from informal feedback and testing gained during the various deployments of *Habitat* together with a consideration of the impact of these changes on the overall system.

Chapter 6 concludes the dissertation, with a summary of the work and its contributions, an outline of the limitations of the system and the scope for further study.

Chapter 2

Literature Survey

2.1 Social Relationships and Connectedness

> Frederick II, a thirteenth-century Holy Roman emperor and king of southern Italy, unwittingly conducted the first study of human bonding. His Imperial Majesty, who spoke several languages himself, thought he could determine the inborn language of mankind by raising a group of children who would never hear speech. Saltimbene de Parma, a Franciscan monk who chronicled the exploits of the experimenting monarch, wrote that Frederick proceeded by 'bidding foster-mothers and nurses to suckle and bath and wash the children, but in no wise prattle or speak with them; for he would have learnt whether they would speak the Hebrew language (which had been the first), or Greek, or Latin, or Arabic, or perchance the tongue of the parents of whom they had been born.' But, the good brother wrote, Frederick's exercise terminated before yielding any linguistic result: all of the infants died before uttering a single word. The emperor had stumbled upon something remarkable: that 'children could not live without clappings of the hands, and gestures, and gladness of countenance, and blandishments.'
>
> A General Theory of Love [1, p68–69]

Research into the physiology of the brain is now starting to unravel some of the issues on why humans have such an affinity to one another. The Limbic brain, which was once believed only to map changes in the external environment to appropriate changes to internal bodily systems [2], is now thought to be also responsible for feelings, moods and emotions. Emotions play a vital part in human communication and the sense of connectedness. The mechanism for the mutual exchange and internal adaptation between two people, whereby they become attuned to one another is known as 'limbic resonance'. It is proposed that the human nervous system is not autonomous or self-contained, but an open-loop system that is continually rewired through intimacy with nearby attachment figures — a process of interactive stabilisation, known as 'limbic regulation'. These processes of resonance and regulation are believed to account for the inter-dependence of two people in a close bond on one another [1]. A spectrum of recognisable states can be observed that provide evidence for these limbic phenomena. For example, in a crowded waiting room a mother detects the nervousness of her child walking into the dentist's surgery. An autonomic exchange occurs; a reassuring warm smile cast toward her offspring and the confident glance returned in acknowledgement. Both parties may feel a sense of calmness and relief. In contrast, the effect of severing these regulating pathways can be devastating. The 'separation anxiety', depression and ill health experienced by those mourning the loss of a parent or child.

In addition, the field of psychobiology provides experimental evidence to support the existence of an array of internal states of awareness and associated biological rhythms. Biorhythms and body clocks are recurring cycles in physiological functions such as sleep and appetite. Biorhythms are regulated by hormones, many of which have a notable effect on behaviour and well-being. Hormonal changes may also be affected by a number of disparate external factors, from environmental light to social contact. Specific agents or events that provide cues to affect or even reset a somatic rhythm are known as *zeitgebers*. It has been well observed that communities of women show a tendency to have their menstrual cycles synchronised. It has been demonstrated that the *zeitgeber* in this case is the exchange of pheromones between proximate females [3, p18].

Scientists have established a causal link between social relationships and health. It was found that more socially isolated individuals are less healthy, psychologically and physically, and more likely to die. These results suggest that the lack of social support, relationships and loneliness constitute a major risk factor for health [4].

Research has also tried to examine whether the Internet as a medium is a communications panacea for social relationships and its impacts on feelings of isolation, exclusion and loneliness. One study initially reported negative effects on social involvement and psychological well-being among new Internet users, describing the effect as the 'Internet Paradox' [5]. The research found that Internet use is associated with increased loneliness; a reduction in both the number of friends people have and the time they spent with them. The fact that the participants used the Internet heavily for communication, which normally has positive effects on relationships, is paradoxical. A follow-up study was undertaken three years later on 208 of the original respondents. The researchers established that the initial negative effects had dissipated but was consistent with a 'rich get richer' model, where Internet use benefited the extroverts and those who had more social support than those who had less support. Some authors suggest a theory for the negative effects of excessive use of Internet found in such studies, hypothesising that Internet use encourages the formation of online relationships, which in turn displace face-to-face contacts. This may result in the overall loss of depth in relationships thought to be important for psychological well-being. Consequently this may lead to increased feelings of loneliness even though the breadth of relationships has increased. A sample of 2006 Americans were surveyed to test this theory [6]. The authors found no evidence for the replacement of face-to-face relationships with online ones in their sample, with the Internet users associated with slightly decreased levels of loneliness. As with former studies, a paradoxical result was found — people that have online friends felt more lonely than those who do not.

One common flaw with nascent works in the study of the impact of Internet use on social relationships and loneliness was that television viewers were primarily used as the control group for comparison. This route may have been taken due to the explosive growth of computers and Internet use in the American home; a trend that seemed to parallel the proliferation of other consumer electronics goods such as televisions and video-cassette recorders. Although the Internet can be used as a broadcast medium like television it rarely is used in this fashion. The consumption of television can be said to be mostly passive and personal - users sit back and watch the medium. The Internet is widely regarded as an interactive, interpersonal, communications medium. Recently launched digital television services now support interactivity, but the medium is relatively under-utilised for that purpose. Another point considering is that it is unlikely that there is a direct correlation between the amount of time users would watch television to the amount of time spent conversing online. A more fitting control group for Internet users would be users of another type of electronically mediated interactive communications medium, such as the cellphone.

2.2 Informal Communication and Awareness

2.2.1 Systems for Face-to-Face Communication

Face-to-face conversation provides a richness of interaction seemingly unmatched by any other form of communication. Naturally, recreating face-to-face was considered the holy grail in telecommunications and researchers presumed the belief in the efficacy of imitating face-to-face communication as a grounding for all further work. This concept of 'being there' by providing rich communications at a distance was heralded by futuristic visions such as the AT&T's *Picturephone*. A prototype system shown at the New York World's Fair in 1964, allowed callers to view each other on small video monitors setup in expanded telephone booths[1]. Telecommunications providers were confident that people would eventually migrate from using telephones to videophones. The increase in quality, capability and availability of technology over time with an associated fall in cost brought about by Moore's Law,

[1] AT&T Technology Timeline — http://www.att.com/attlabs/reputation/timeline/70picture.html

gave research labs the opportunity to develop systems and build infrastructures to experiment with audiovisual communications between remote sites. Until this point video had proved a great success as a medium for broadcasting entertainment but was unproven as a medium for interpersonal communication.

The *VideoWindow* project at Bellcore telecommunications laboratory, aimed to recreate the informal interactions between workers [7]. The *VideoWindow* system linked together two common areas on different floors of a building, allowing remote co-workers to converse using a large window-like display equipped with cameras and microphones. A study undertaken during a 3 month long deployment of the system showed that for informal interactions, users found the *VideoWindow* system somewhat lacking for a variety of technological and social reasons. The researchers concluded that the system did not provide the same degree of social intimacy as face-to-face interaction.

At this point, some researchers had begun to question whether the belief that creating the face-to-face experience should be the ultimate ideal of telecommunications. A seminal paper entitled *Beyond Being There* by Hollan and Stornetta deconstructed this supposition[8]. The authors explain that the quality of telecommunications technology will incrementally improve and will eventually reach a state where the fidelity of the audio and video will be so close to 'the real thing' that for most needs it will be indistinguishable. Using such a system may be a cost effective alternative to long distance travel. But would these systems ever reach a point that those at a distance will be at no real disadvantage compared with those colocated? As shown with with *VideoWindow* and other audiovisual experiments of that time, Hollen and Stornetta suggest that such systems may never be close enough. They elaborate on their hypothesis by stating that a fundamental difference will always remain, as long as people use one medium to communicate with those at a distance and another for those for whom distance is not an issue. Instead, communications tools need to be developed that people prefer to use even when they have the option of a real face-to-face interaction.

The authors put forward a rather apt analogy that highlights this point, capturing much of the essence of prior telecommunications research: "Perhaps we have been building crutches rather than shoes." Crutches are used as supports and only used when fully functional legs are not available. Shoes are used to augment legs and are used even when legs are fully functional. One familiar example of a communications technology that provides 'shoes' is electronic mail. In some situations it is preferable to send an e-mail rather than have a face-to-face conversation. For instance, in a work setting, sending an e-mail avoids disturbing co-workers from their main activities and allows them to respond at their convenience.

2.2.2 Media Spaces

Being near others, whether sharing a house, working in adjacent offices or living in the same city, gives people certain opportunities for interaction that are unavailable to those not collocated. Relationships of all kinds require active participation from its members to maintain bonds. This is also true in the work place where good quality relationships are equally important to help get work done. The informal interchanges that occur frequently between co-workers are considered a vital part of the bonding process that underlies later work activity. These casual exchanges usually occur outside of formal meetings. Many large organisations find that as they expand out to other locations, working together becomes increasingly difficult. When people are geographically separated, much of their informal knowledge about each other disappears and communication becomes much more formal. This formality in communication can have a negative impact on the ability to collaborate with remote colleagues. Researchers at large industrial laboratories realised that the issue of collaboration over a distance would be one they would be increasingly faced with in their working life. Thus a new branch of research was formed around such issues of collaboration, awareness and informal communications — Computer Supported Co-operative Work (CSCW). This was a departure from previous approaches that focused on the technology behind electronically mediated communication rather than the users.

The *Media Space* work [9] at Xerox PARC aimed to foster collaboration and maintain the culture between researchers across the organisation at different locations. The central premise behind the research is that work is fundamentally social and a requirement of the *Media Space* was to integrate both casual and task specific communication. The *Media Space* was similar to earlier projects like *VideoWindow* but on a much larger scale both in number of connections and the distance. The *Media Space* linked two sites: Palo Alto, California and Portland, Oregon. A total of thirty nodes were connected, bridging a distance of over eight hundred miles. The PARC system was not developed using a top-down model but rather as a system built by researchers, for researchers.

The system evolved over a number of years between 1986 and 1991, during which time it was in almost continual use. This allowed the researchers a substantial period of study and observation. The *Media Space* was formed by linking together the offices and common areas across the two sites with video cameras and microphones. The facility to switch connections between each commons area or an office was manually controlled by the users, allowing them to converse with whom ever they desire. Users were free to control their privacy by manually unplugging cameras or microphones. The underlying platform merged audio, video and computing through the multiplexing of several high bandwidth communications links. The developers of the system took the view that what they had created should become a generic term for a communications platform, a 'media space', that has the following qualities:

> An electronic setting in which groups of people can work together, even when they are not resident in the same place or present at the same time. In a media space, people can create real time visual and acoustic environments that can span physically separate areas. They can also control the recording, accessing of recorded images and sounds from those environments. The goal of a media space should not be to replace or replicate face-to-face communication, but to support communication and sustain relationships that are not possible without 'being there'.
> Stults, R., Xerox PARC (1986)

The researchers noted a number of pertinent observations from the long deployment of their work that may have implications for all media spaces [10]. Firstly, a media space links together places, not just people. Whereas previous communications technology can be said to appropriate physical space to merely support the communications (e.g. a telephone booth), a media space uses communications technology to alter and augment the physical spaces that are linked. Secondly, the act of using a media space is not primarily an activity in itself, but one that enables other activities. Unlike 'telephone', 'media space' was not a verb. Finally, a media space had many uses such as locating colleagues, video conversations, group discussions and presentations, but it was observed that the most powerful use of the system was for peripheral awareness [9, p34]. It was found that the the most often viewed subject in the *Media Space* was the commons area. Audio from one remote commons area gave the person in the remote office or other commons area a background awareness to who was around at the other site. Lab members who were working closely together would often have view of each other's office for the same purpose.

Researchers at Xerox further investigated the issues in supporting a shared peripheral awareness amongst distributed work-groups with a later project, *Portholes* [11]. The project ran between Xerox PARC in Palo Alto, California and EuroPARC in Cambridge, England. The system infrastructure was similar to *Media Spaces* in that it provided an always available bi-directional link but differs in the style of the connection. The *Media Spaces* provided real-time synchronous video communication, whereas *Portholes* provides (mainly) static images from the remote sites in an asynchronous connection. The interface to *Portholes* consists of a large screen that has a grid of images (with identifying captions) from each video camera linked up to the system. The images update approximately every ten minutes. The intentions of the *Portholes* project were to create a meaningful, low bandwidth 'lightweight' awareness system. Lightweight meaning that the system presents information without requiring any user intervention or any distraction from their main activities. *Portholes* used much less bandwidth than *Media Spaces* since live video was not being transmitted over the network. A small study was undertaken to examine the effects of the system. Fifteen users were asked to keep a usage diary for three days and fill out a questionnaire. Feedback was generally positive and the authors suggested three areas for further investigation. Firstly, the effect of awareness information on a workgroup. Next, the ability of an awareness system such as *Portholes* to provide meaningful and useful information. And lastly, considerations in the design of interfaces to present awareness information.

The systems developed by Xerox were largely successful because they were developed by the researchers for their own use. The developers generally responded to most of their users' needs, understood their concerns about their privacy and their needs to modify and personalise [12]. There was symbiotic evolution in the technology used in the systems and the work activities around the systems that created that technology. Not all media space style systems took this approach or achieved success — some failed for a variety of technical and social issues [13]. For example, a community building system developed by Microsoft Research that linked three kitchen areas between two campus buildings. In comparison to the approach taken by Xerox researchers, the Microsoft system was poorly designed and engineered from both a social and technical standpoint. One major flaw in the communication system was the audio - the quality was deficient and a distracting echo persisted throughout the systems overall deployment. The developers did not sufficiently address the users' privacy concerns. The authors also controversially note that a hostile minority of users sabotaged and damaged their system regularly. The key lesson to be learnt here is that a system was forced upon users who did not want or need it.

2.2.3 Awareness Systems on the Desktop

Previous media spaces were built using separate audio, video and computing systems and network infrastructures multiplexed together. This made it costly to expand in scale and complex in terms of switching and control. The processing power of computer workstations and the bandwidth of networks had improved to a point in the early 1990's where it was feasible for media space concepts to begin to appear on the computer desktop. Computer servers and local area networks were able to handle the processing, transmission and switching of audio and video data feeds direct from the computer desktops of users.

Researchers at Sunsoft developed a computer workstation based awareness system for distributed groups called *Montage* [14]. Their motivation was to create a system that helped the users find opportune moments times to interact with one another, by providing a sense of proximity. Early in the design process the developers proposed that the system required a familiar and consistent metaphor to provide this ‘teleproximity’.

Conventional communications systems such as the telephone adhere to a simple model of interaction. This model does not make any attempt to find an opportune moment for communication. The person being called has to explicitly respond to the call request by answering a the ringing telephone. Obviously disturbance and distraction is caused to the called party if it is an inopportune moment. The caller does not get any feedback prior to calling on whether it is a good time to call.

The approach taken by media space style projects such as *Portholes* can be said to be a *surveillance* model. The users study an overview of all the other users’ cameras to get a sense of what is happening at a variety of locations. Under certain contexts for some close-knit work-groups this solution may be appropriate. Some people may be uncomfortable with the idea of their image being broadcast and not knowing who may be watching.

The authors propose a *hallway* model for *Montage*. This interaction model reflects what happens when someone walks down a corridor in an office looking for a colleague. As the office is approached, sounds from inside may give a clue that someone is present. The occupant may also hear the approaching footsteps and prepare for a visitor. On arrival at the colleagues’ office door, if the door is open or has a glass pane, the visitor is able to look in to see if their colleague is busy or available to talk. People may block access by closing their doors or allow access by leaving their office door wide open. Privacy is socially negotiated, largely through auditory and visual cues. The hallway model has less potential to disturb than the telephone model but it does not provide the same level of protection of privacy (ignoring the ringing telephone or unplugging it). Since people can see who is looking in from the hallway there is less concern about snooping as with the surveillance model.

Users of *Montage* access the system though a desktop application on their computer workstation. Each workstation has a small camera and microphone attached to the computer display. The user selects another user to perform a 'glance'. This causes a small video image of the called party to fade into the display of the caller. Simultaneously a reciprocal video image of the caller fades into the display of the called party (along with a notification sound). The users can now see each other for a period of approximately eight seconds. During this glance operation, the remote user may accept the call and they move into a full two-way video-conference. Audio is not enabled during the glance to maintain privacy, in case the called party is caught unaware having a conversation with someone in their office. If the person glancing sees the called party is absent then they have the option to leave a note. Users also have access to a do-not-disturb mode where others may not glance in. At the end of development, a nine-week study of a group of six users was undertaken. Logs showed that the *Montage* application usage was sustained throughout the group and 653 glances were made, of which 31% resulted in video conferences.

Sunsoft researchers continued working on further CSCW prototypes to extend their findings. Three years later, *Piazza* was developed to provide a rich desktop communications platform for impromptu and planned interactions [15]. This system had a range of communications and workgroup applications. Some elements of the system supported more informal and unintentional conversation between workers. The glancing mechanism developed earlier was also incorporated. Only 31% of glances went on to become full video conferences in *Montage*. One reason was due to called parties being out of their office or unavailable. *Piazza* addressed this problem by explicitly maintaining availability information of its users, therefore callers would have knowledge of whether someone was at their desk and available before a glance was even attempted.

2.2.4 Telepresence and Shared Spaces

Presence, the quality of ‘being there’, is taken for granted during face-to-face communication. All participants are ‘present’ together in the same space. In electronically mediated conversations, participants inhabit a virtual space that spans the geographical or temporal distance between one another and where they have a distributed virtual presence. This ability to achieve presence over a distance is commonly referred to as ‘telepresence’. Different communication media afford subjectively varying levels of telepresence. Virtual places maybe created in an ad-hoc fashion or maybe permanent venues (e.g. an e-mail discussion list).

During a telephone conversation, auditory information from the location of each caller forms a new (audio only) shared space. Even when one party is not speaking background noise or breathing sounds provide presence information, cues that indicate that they are still connected and listening. Traditional multi-party video conferencing systems can be said to offer a greater degree of presence compared to the telephone. Visible non-verbal cues such as body language, gaze direction, eye contact and other gestures reinforce the communication. Although these are positive factors that enrich video conferencing, such systems have not been designed with the concept of creating a shared space for its participants at their core. Some manufacturers augment their video conferencing systems with shared electronic whiteboards as an attempt to create a shared space for sketching out ideas. Even so, a typical video conferencing experience usually means each participant’s video is confined to a single window — underlining a mood of separation rather than togetherness. Such a communications space may be thought of as unnecessarily divisive, formal and even confrontational. These factors alone could impede informal and natural collaboration activities in the workplace.

Criticism directed at the failure of video-conferencing systems to adequately create a shared space should be balanced with an acceptance of how such systems were developed. Historically, telephone booths were the norm, where each caller had an individual cubicle. Since early video conferencing systems were extensions of the telephone booth concept it seemed natural to have each caller in a separate video display. At that time it was not technically feasible to have more than one video channel to a single display. Also, it is highly unlikely that communications engineers and designers of early telephone systems had the creation of a shared space in mind from the outset. It is more likely that the shared space concept is a subtle abstraction to a technical side-effect of overlaying multiple audio channels.

Eventually technology allowed the creation of a shared space in videoconferencing by merging together separate video feeds so that all participants share one virtual scene together. *Reflection of Presence* [16] and *HyperMirror* [17] both independently developed this idea albeit implementing different techniques. The use of mirrored video alone in CSCW applications is not new — *ClearBoard* [18] used a single mirrored video feed projected behind the surface of drawing boards to allow collaborating designers to work together.

Reflection of Presence uses computer vision algorithms to extract each subject from their background and reassemble them onto a shared scene. The system employs spatial audio so that sound appears to emanate from the location of each participant in the scene. Functionality to support the collaborative nature and group dynamics of video conferences is a key part of the system. The system continually detects who is the centre of attention, i.e. the participant that is currently talking the loudest. That participant's video image is bought forward to the front layer of the display, whilst the listening participant's images fade into the background by becoming slightly less opaque. This effect reinforces the prominence of the speaker, but still allows the speaker to see that the others are listening. A natural and fluid transition occurs from speakers to listeners.

HyperMirror uses analogue chroma-keying for extraction (the 'green screen' technique used in TV weather forecasts) and mixes the video together. The advantage of *Reflection of Presence* is that it uses standard personal computers on a LAN, therefore is much more scalable and flexible. On the other hand, *Hypermirror* performs all its extraction using video hardware which tends to give better reliability and performance, compared to processing complex software algorithms on a personal computer as with *Reflection of Presence*. One common drawback for both systems is that since they use mirrored images, reading text or drawings held up by the participants is difficult as everything is back to front. *Reflection of Presence* finds a way around this by supporting a mode where a slide-show can be presented on the shared background for everyone to view and discuss. The developers also support a 'TV mode' where a movie or TV channel can be displayed as the background — the participants' images are shrunk down so that only their heads are displayed at the bottom of the display. The scenario is one where a family who may usually watch a movie together cannot due to some members being away from home. Watching the movie using *Reflection of Presence*, the family members' faces appear transparent, but in a moment of comedy the laughter from each person makes their faces opaque — so everyone can see their smiling facial expressions and hear their chuckling. This is a rare feature as most CSCW systems almost exclusively concentrate on workplace communications problems of businesses, rather than the leisure and social issues in the home.

BT Related Work

A number of projects ongoing at BT's research labs are relevant to this discussion. Investigating the informal nature of workplace communication, Thorne [19] has developed *Aware* a system that creates an open audio-visual connection between a small group of colleagues. Each user has a webcam at their workstation. The video feed is transmitted to each of the other users' workstations. Each workstation displays these video feeds in semi-transparent windows arranged in a column, floating above other application windows on the left-side of the user's screen. These video windows provide an always open communications channels to maintain a sense of awareness. To maintain a level of privacy, only low volume background noise is transmitted and the video feed is looped over a few seconds. This provides feedback to observers about the presence and activity of each user at their desk.

Examining the collaboration and telepresence aspects in distributed teams, *VIRTUE* aims to recreate a shared, immersive, virtual reality environment incorporating live video, virtual 3D actors and objects [20]. The system supports a number of conversational cues such as natural gaze direction, eye contact, hand gesturing and body language.

Creating a sensing infrastructure for providing care to the elderly and infirm, *Telecare* work is currently being put in trial with local authorities in Liverpool [21]. The work analyses a large data-set gathered from passive-infrared motion sensors in a number of homes. A mathematical model was developed to tune the sensitivity levels of sensors and help determine a response time for care providers when no activity is detected.

2.2.5 Awareness in Co-located groups

In contrast to the projects described previously, one vein of research took the idea of moving awareness technologies away from applications that inhabited one user's personal workstation and into the common office space so that several people share its use. *Aware Community Portals* [22] is an effort to create 'Shared Information Appliances' that are installed in areas where co-workers pass through. The 'Aware Community Portal' takes the form of a large projected display that users interact with using movement, proximity and glancing. The display is placed in a social setting between personal offices, a similar approach to that of the 'commons' area in *Media Spaces* [9]. The content provided by the system was a filtered stream of primarily news, weather and an e-mail lists repurposed for the display. The system monitors people moving through the space using video cameras. A user pausing to read a headline on the display can be detected. If the user decides to stop and look at the display for a short duration, the cycling of the information feed would pause to reveal further detail information for instance a short summary of the news story associated with the headline.

To alleviate privacy concerns of using video cameras in the workplace, the display also incorporated a small window playing back the video feed from the camera, so the users could see what is being captured. The awareness element of the system focuses on providing presence information to co-workers. A user reading the display has the opportunity to look directly at the camera. This event triggers the system to capture an image of that user's face. This face image is presented along with the news item, giving subsequent users an awareness of who else may have read the article, hence a notion of which co-workers were around recently. It also gives an indication to how popular a particular information article is.

Additionally at the bottom of the display, a time-line is displayed to provide a trace of the movement through the commons area. Anonymous users appear as small squares, but the people that have browsed the story through 'glancing' have a thumbnail of their face displayed on the time-line — giving a clear indication of when they were last in the area. Since *Awareness Community Portals* employs only movement, proximity and visual cues to operate the system it successfully meets its aims to develop very lightweight techniques for awareness and interaction in shared workspaces.

Semi-Public Displays [23] is a second example of a shared information appliance designed to provide awareness between members of a small community or work group. The *Semi-Public Display* prototype is designed for a small group of members in a research group. It consists of a large touch-screen computer display placed in the commons area of the researchers. The display is dividing into four quadrants of roughly equal size.

The first quadrant of the *Semi-Public Display* is a collaboration space, taking the form of a free space for the researcher to scribble down ideas or questions using a graphics tablet. The motivation to include this function was to encourage asynchronous brainstorming among the researchers.

The second quadrant is an 'active portrait', a group photograph of the researchers. The system software manipulates each member's image to reflect their presence in the lab. The presence information is obtained by monitoring each researcher keyboard activity in a similar fashion to Instant Messenger applications. A researcher who doesn't use their computer for a period of time is registered away and the *Semi-Public Display* alters their image so that becomes gradually lighter. This approach of obtaining presence information is somewhat flawed since a researcher may be sitting at their desk reading rather than using the computer. A way around this problem may be to average the keyboard usage data over a longer period, so that if the computer is not used for several hours then the system registers that person as away. A down-side to this approach is that it does not accurately inform the viewer whether a person is there or not. Also the choice to 'bleach out' area of group portrait for researchers that are not present could be visually distracting and detract from being able to recognise the person. A better choice may have been to alter the opacity or saturation of the image.

The third quadrant is a place for reminders, brief requests or facts. The information for this section is fed from the group e-mail alias. Typically the researchers post a message via e-mail for instance asking for help with a conference submission. This message is displayed on the *Semi-Public Display* for other researchers to respond to or simply be aware of the other group members workload.

The fourth quadrant of the display is an 'attendance panel'. This takes the form a graphical record of upcoming events visualised as 'attendance flowers'. One 'flower' is displayed for each event. Each flower consists of a large central circle containing a hidden label denoting the event. The central circle is surrounded by a number of smaller circles or 'petals'. One petal for each researcher in the group. The researchers can then anonymously denote their intention to attend a particular event by first touching the centre of the flower to reveal the event name and then touching one of the petals. The colour of the petal changes to reflect attendance, non-attendance or undecided. This is a novel approach to capturing the groups intention to attend an event and could be said to be a rather more intuitive to understand than the traditional method of browsing through the groups individual calendars (some of which may not be shared). The authors state that it provides viewers the ability to glance at the flowers and quickly gain an awareness of how many people will attend an event. The advantage and elegance of this is taken away by the fact that users still have to walk up to the display and touch the centre of the flower to reveal the event name. A poor design choice as it requires the user to physically do something rather than simply glance at the display as per *Aware Community Portals*.

Questionnaires were used to evaluate the *Semi-Public Display* system. Both open-ended questions and 5-point Lickert scales were used to assess the four applications. The results captured some of the criticism noted above — users found it difficult to distinguish people in the 'active portrait' due to the image appearing washed out. Also respondents questioned the accuracy of presence information coming from keyboard activity alone.

2.2.6 Ubiquitous Computing and Calm Technology

Eventually researchers began to question whether the telecommunications approach taken so far in providing an audiovisual facsimile of a remote partner was actually required to provide awareness. Researchers at Xerox PARC began to imagine a future where the growth of the Internet and distributed processing, results in the widespread proliferation of connected computing devices, eventually leading to an era of *Ubiquitous Computing.* Mark Wieser, the founder of this movement, sets out ideas and goals for this field in his seminal paper, *The Computer for the 21st Century* [24]. The key argument of the paper is now universally accepted and taken for granted:

> Specialised elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence.

Developing these ideas further, Wieser and Seely Brown present the case where ubiquitous computing, characterised by deeply embedding computation into the world, will require a new approach to fitting technology into people's lives — an approach they refer to as *Calm Technology.*

> Designs that encalm and inform meet two human needs not usually met together. Information technology is more often the enemy of calm. Pagers, cellphones, news-services, the World-Wide-Web, e-mail, TV, and radio bombard us frenetically. Can we really look to technology itself for a solution?
>
> But some technology does lead to true calm and comfort. There is no less technology involved in a comfortable pair of shoes, in a fine writing pen, or in delivering the New York Times on a Sunday morning, than in a home PC. Why is one often enraging, the others frequently encalming? We believe the difference is in how they engage our attention. Calm technology engages both

> the centre and the periphery of our attention, and in fact moves back and forth between the two.
>
> *The Coming Age of Calm Technology* [25]

An early work in the area of *Calm Technology* is *Feather, Scent and Shaker* [26], a range of simple networked systems aimed at supporting implicit, personal and expressive communication — intimacy over a distance. The first system, *Feather*, was designed for situations where one partner is travelling and the other stays at home. The prototype had two elements. The first is a small object such as a picture frame, that the traveller can take with him. The second part is much larger and meant to be a relatively stable feature of a home, like a piece of furniture. The item designed for the work is a decorative piece that is essentially a tube containing a feather and small electric fan. When the travelling partner lifts the picture frame, a circuit is completed to the second device causing the fan to make the feather float. The aim is to indicate when the travelling partner is thinking of the other.

The next system prototype, *Scent*, is a variation on Feather. Again the traveller takes a memento object such as a picture frame away with him. However, in this system the picture frame is connected to a remote bowl of fragrant oil. Manipulating the picture frame causes a heating element in the bowl to vaporise oil, filling the home space with scent that lingers for some time.

The final set of devices in the series, *Shaker*, allow for a more symmetrical communication than the previous two prototypes. Each person is given a pair of devices, a sender and a receiver. When one partner shakes their sender, the other partner's receiver shakes proportionately.

The prototypes developed in this work are good early examples in providing abstract notions of presence and awareness, in line with the Calm technology meme. *Feather, Scent and Shaker* was developed primarily by non-technical designers and therefore is more an art piece than a fully functioning technology. The devices may have had more impact if they were wireless rather than tethered by cables. *Feather* could be criticised for a couple of reasons. Firstly, the interaction between the traveller and the person staying at home is purely one-way. The home user has no way of using the system to express feelings back to the traveller. To be fair to the artists, they recognised this short-coming and address it with *Shaker*. Another point of contention is that the picture frame is quite a realistic item that a traveller may take with him on a trip. Whereas the 'feather' acts as a custom display object unlike any other piece of furniture in the home, It may well be that the designers intend the 'feather' to have a dual function — one as an awareness device and two as an 'art piece' in the home, much like any other figurine or painting. *Scent* is a novel and worth variation that allows the remote user to let his presence linger for an extended period of time, compared to *Feather*, where if the home user is away the message may not be viewed. The main contribution of the work is that it proves that simple awareness at a distance can be achieved using a strategy of abstract and symbolic expression — an approach largely ignored in CSCW research at that point.

2.2.7 Ambient Media and Tangible Interfaces

Soon after the advent of the *Ubiquitous Computing* and *Calm Technology* concepts, led mainly by Xerox PARC, other researchers began to develop complementary ideas. The work of Isshi et al from MIT Media Lab was instrumental in defining several new human-computer interaction metaphors. *Ambient Media* was a phrase coined to describe systems designed specifically to take advantage of peripheral awareness. Human perception allows information to be processed in the background, without necessarily demanding attention or impeding the foreground activity.

The *ambientROOM* project [27] was the first of such demonstrations to single out this aspect of awareness. In an office environment, a small self-contained area was created as a personal work-space. Various information feeds were then fed into this space, each represented by a different method. For instance, on the ceiling of the *ambientROOM* a projection of gentle water ripples was made to denote the activities of a pet. The speed of the lab hamster running inside the wheel of its cage was reflected in the speed of water ripples moving across the ceiling. Against the walls of the workspace light patches were projected to reflect the movement of co-workers around the lab.

Sound was used to represent a range of information. For example, the sound of a bird singing when the users share portfolio was doing well on the stock market. The researchers also developed a range of 'graspable media controls' to manage the ambient activity. A simple bottle interface acted as container for information streams. A user would uncork a bottle to 'release' an information stream into the room. Another control device took the form of a clock. Moving the clock hands backwards or forwards acted as a kind of jog-dial to shuttle back and forth in time to replay information visualisations in the room. This feature would allow absent users to check on what had happened while they were away.

In general *Ambient Media* interfaces aimed not to overload one particular sense of perception. Several projects examined other senses (modalities) that could be used for peripheral awareness. The majority of the work stuck to using one sense (i.e. purely visual) but some researchers explored systems that spread the 'perceptual load' over several senses (multi-modal interfaces). One example of using smell as medium for information exchange was *inStink* [28]. This work was successful in developing a computer controlled mechanism to release smells into the kitchen spaces of two remote partners. *ListenIN* [29] was a similar project that used sound to link together a traveller with his home environment. In order to protect privacy, the sound transmitted was subject to a 'garbling' algorithm that obscured the sounds so speech could not be eavesdropped.

The *ambientROOM* was important in many respects for reviving interest in peripheral or ambient awareness. The use of abstract representations was a departure from using live video as used in the *Media Space* projects. This was significant since it reinforces the argument made by Holland and Stornetta about face-to-face communication. By dropping support for live video and focussing purely on peripheral awareness there is no chance for direct, formal, two-way communication. This tends to predicate that *Ambient Media* is confined to informal communication only; the exact feature that early CSCW researchers were so passionate about. It should be noted that the *Media Space* agenda is not completely divergent and it is apparent that it still informs some aspects of ambient projects. For example in the *ambientROOM* the facility to use the clock interface to replay previous experiences is a feature explicitly mentioned in the definition of a media space. Therefore it is suffice to say that *Ambient Media* are modern day cousins of the traditional media space, retaining some features but focussing on abstract representations of presence. Pederson et al. derived a framework for an ideal abstract awareness system [30] after examining the approaches taken by early CSCW and *Calm Technology* projects.

The graspable media controls detailed in the *ambientROOM* were the fruits of parallel developments in *Ubiquitous Computing*. The seemingly invisible embedding of computation into everyday materials as described by *Ubiquitous Computing* led to another interaction metaphor by Ishii. *Tangible Interfaces* [31] married physical objects to digital information. Artefacts, embedded with sensors or other computational functionality, are bound to an underlying digital model. A prototype tangible interface was an architecture-planning tool created to help design buildings and their impact on the surrounding environment. The prototype consisted of a table with several artefacts in the form of model buildings. The positions and orientations of these buildings placed on the table were sensed in real-time and overlaid with an information display. As buildings were reorganised the architect could view various aspects such as the flow of wind around the buildings or the shadows cast. Several dials could be placed on the table to modify parameters such as wind speed or time of day. This work introduced a simple, intuitive and effective interface to a complex activity. Several projects took the tangible interface concept outside of a work context, also supporting ambient awareness applications. *LumiTouch* was a pair of picture frames that acted as a tangible interface to a loved one [32]. When one partner picked up a picture frame, the remote picture frame would light up. The idea was that a symbolic language would develop from this activity. For example, a lit picture frame could be a signal that their partner is thinking about them. Or it could mean "call me." *The Bed* was a project that provided abstracted presence for intimate, non-verbal communication. The system consisted of two networked beds. Many input/output mappings were supported by *The Bed*. A partner lying down on one bed would cause the remote bed to warm up. Microphones were embedded in the pillows to pick up breathing sounds of a sleeping partner. This sound was used to blow curtains gently at the remote end.

Another project using furniture to convey awareness in close relationships was *Peek-A-Drawer* [33]. This system was designed to maintain a link between grandparents and their grandchildren. The prototype consisted a pair of natural looking chest of drawers. An item placed in the top-drawer would trigger a digital photograph to be taken and sent to the remote chest of drawers. The remote party would periodically check the lower-drawer of their chest of drawers. The lower-drawer had a flat-panel display embedded inside to display the photograph of the remote objects. Even though the communications needs of the children compared to the grandparents differ, *Peek-A-Drawer* provides a symmetrical awareness medium. The same group of researchers developed further work in lightweight awareness. The *Digital Family Portraits* project was a feasibility study aimed to provide peace of mind to extended family members. Again the researchers targeted grandparents and grandchildren. Digitally augmented portraits would show activity levels of remote relatives to provide reassurance. The feasibility study established the requirements of such a system by conducting a small field trial. No physical devices were developed, but data was collected by telephone interview. Mock-ups of the digital portraits were created using image files that were e-mailed between the participants of the trial. The project established a need for such a system and the researchers planned to build a prototype system with a sensing infrastructure to automatically generate the digital portraits.

2.2.8 Evaluating Awareness Systems

By far the most significant shortcoming of that vast majority of the work in awareness systems is the lack of extensive user studies. Most of the research papers reviewed here have called for proper trials of the technology they have developed. Some have suggested specific questions for examination. Few have actually generated any meaningful data. As the technology, concepts, research methodology and field is maturing these issues are beginning to be addressed. Holmquist [34] postulates the reasons for the lack of useful evaluations to date are that ambient displays require long-term installations, the usage intensity is low — perhaps a user may only glance at an ambient display a few times a day. There observational studies would be time consuming and difficult to perform. He also notes the lack of clear evaluation criteria. He argues for three levels of comprehension to be evaluated. Each level is a perquisite for the next.

1. *That* information is visualised.
2. *What* kind of information is visualised.
3. *How* the information is visualised.

A recent and important development is the Affective Benefits and Costs in Communication Questionnaire (ABC-Q) developed by van Baren et al. [35]. This work focussed on capturing qualitative data about feelings, attitudes and behaviours towards communications technologies. The questionnaire does not measure social presence or communication effectiveness. The questionnaire does facilitate the comparison of ambient media technologies with more traditional technologies such as telephony and e-mail. This is a welcome addition to the limited spectrum of measurement tools in telecommunications.

2.3 Motivation and Basis for Thesis

This literature survey exposes a number of shortcomings in previous approaches to awareness systems. These gaps and deficiencies provide the motivation and opportunities for new research.

One obvious area to investigate is the nature and form of the interaction model underpinning the awareness. Some systems only provided a very subtle notion of awareness in an unidirectional manner. For instance, *Feather, Scent and Shaker* allowed the partner at home to be aware that the remote partner was 'thinking' about them. The remote partner had no clue to when the home partner was doing the same. This unidirectional nature of the interaction could potentially create an imbalance of awareness information between two people in a close-bond. Other projects, such as *Portholes*, offered bidirectional information. Each user was able to access the same awareness information, in this case small snapshot images of people at various locations in a research organisation. The downside to this approach was that a 'surveillance' model was used; the observed had no clue to whom the observers were and when observation was taking place. This led to users being concerned for their privacy. Although the impact on the infringement of personal privacy between people in close bonds may often be less of an issue than in other types of relationships it is still a valid concern. Simply offering bidirectional communication of awareness does not alleviate such concerns. Eventually 'surveillance' worries were countered by systems that offered reciprocity. *Montage* and other systems offering the ability for users to exchange bidirectional, reciprocal 'glance' type exchanges reinstated a more natural and familiar interaction model to users.

Another trend in the reviewed work was the balance between automatic, passive and manual, active interaction with the awareness systems. For example, users of *Media Spaces* were obliged to manually switch between audio and video feeds between office and commons areas. This allowed the users to exercise complete control over who and what they were aware of. Other systems, such as *ambientROOM*, projected awareness information in a lightweight manner in the periphery of the user's attention, with view to creating the minimum of distraction. Some research provides a mix of the two modes. *Semi-Public Displays* required the users to manually interact with the system to denote their intention to attend events. Whereas presence information to indicate whether a team member was in the office was collected in transparently in the background by sensing their keyboard activity.

The completeness of the awareness systems reviewed varied from conceptual studies that concentrated on developing a valid methodology with no physical instantiations built (*Digital Family Portraits*) to well established, mature long-term deployments (*Media Spaces*) of fully functional technology. The bulk of the work fell into the category of working prototypes that were suitable to demonstrate the projects concepts and conduct a short-term trial. Some projects (*Feather, Scent and Shaker*) were more along the lines of art pieces that were designed to raise as many questions as they answered. The technical complexity of projects also varied greatly. Systems such as *VIRTUE* drew upon custom hardware and computationally complex software algorithms compared to simplistic devices such as the *LumiTouch* picture frames. Respectively, bandwidth requirements were these projects were poles apart.

The conclusions drawn from the above provides a starting point for further work, as detailed in the rest of this thesis. In summary these points are:

1. Create a bidirectional, reciprocal communication platform.
2. Allow users to retain manual control of their participation and privacy, but don't let the system get in the way.
3. Aim to minimise computation complexity and bandwidth costs.

One final desire would be to develop a system that fits Holland and Stornetta's ideal of creating 'shoes rather than crutches', that is a technology that partners would use irrespective of whether they were distant or physically proximate.

2.4 Summary

This chapter has presented a range of prior research in the field of technology-mediated relationships. In particular, the examples have centred around systems that provide awareness for people in a variety of social and working relationships. The section ends with a number of conclusions drawn from the body of previous research and how it may shape a potential solution to the problem of creating awareness-over-a-distance.

Chapter 3

Method

3.1 Habitat - A Prototype Awareness System

A concept demonstrator based around networked furniture was built as an attempt to address the needs of people in long distance relationships. The prototype system was developed to illustrate how everyday objects and items of furniture could be employed as a novel interface to capture and communicate awareness. It was also planned to use the system as a testbed platform for further studies and experiments in the field of awareness.

The prototype system consisted of two identical stations that were networked together. The user's point of interaction with the system was a coffee table placed in their living area. Other components (figure 3.1) such as a computer, tag-reading system and a projector were kept as hidden as possible from the user. For convenience during development these *Habitat* stations were located a few metres apart and linked over the local area network, although the system was designed to function over a wide area network (such as The Internet) for deployment in real-world trials.

3.2 System Elements

Each *Habitat* station was designed to be installed as an appliance in a users home — to be always-on, available and connected. A typical installation

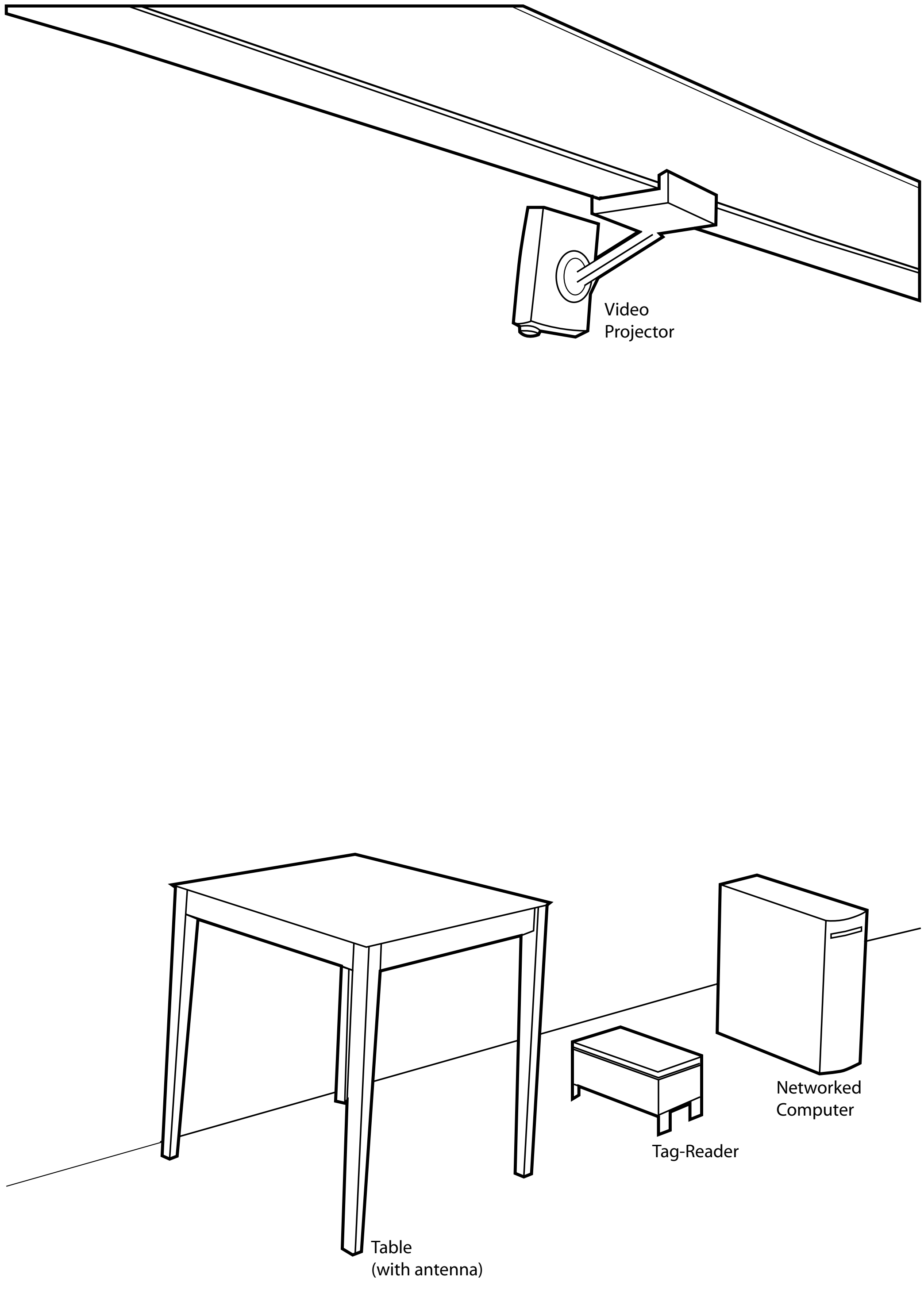

Figure 3.1: An Overview of the *Habitat* system.

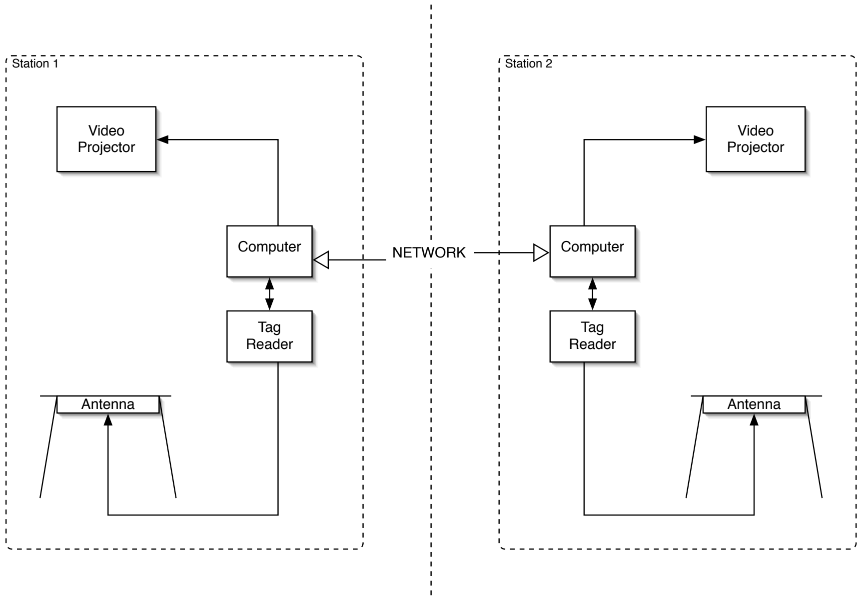

Figure 3.2: Logical Layout of System Elements.

consists of a number of subsystems (figure 3.2). Each subsystem was an off-the-shelf item, with modifications where necessary to conceal the underlying hardware from the users.

3.2.1 Video Projector

Each station incorporates a video projector to display the awareness information. The projectors are capable of reproducing high-resolution graphics (1024 by 768 pixels). The projector was vertically mounted from the ceiling, using standard UNICOL type brackets, pointing down over the table. The mounting bracket together with the projector controls provided a means to adjust the image during final setup. Mains power and video cables were routed away from the projector toward the computer system on the floor nearby.

3.2.2 Networked Computer

The computing subsystem comprised of a standard configuration personal computer. Networked connectivity (wired or wireless) is required but otherwise no specialised components are required. The *Habitat* system software was developed using Isis[1], an interpreted language for responsive media applications. Isis currently runs under Linux or Apple Mac OS X operating systems. The computer was connected to mains power, video output to the projector, ethernet connection into the LAN, RS232 serial connection to the tag-reader and a keyboard and mouse. During a deployment, the computer is booted and a copy of the *Habitat* system software is executed.

3.2.3 Tag-reader

The tag-readers used were standard (ISO 15693) RFID (Radio Frequency Identification) hardware manufactured by Texas Instruments (S6550 Long Range model). Each tag-reader was used with a square gate antenna. The tag-reader was positioned beside the networked computer. The tag-reader was connected to mains power and its serial cable connected to the the PC. An extended length of shielded coaxial cable was routed from the tag-reader housing and run toward the table at the centre of the installation.

3.2.4 Table

The main element of each station was a freestanding coffee table. A table was chosen because it satisfies the requirement that it is an everyday item in the majority of households. Tables have large flat surfaces on which are always in easy eye-fall of users and hence useful for display of information. Although the exact style and design of the coffee table was not important the material of the tabletop had to satisfy the following conditions. Firstly, there had to be sufficient free space underneath the tabletop to mount the antenna of the tag-reading subsystem. Tabletops with metal struts or a central pole attached to them are not suitable since they would impair the antenna's ability to detect

[1]For more information on Isis please consult Appendix B.

tagged artefacts. Secondly, the tabletop material must again be non-metallic and not thick enough to have an adverse affect on the range of the antenna to read tagged artefacts through the tabletop. Finally, the tabletop surface must be somewhat matt and uniformly plain to ensure directly projected images are clearly visible.

The tabletop was lifted off the table (figure 3.3) to install the gate antenna. A simple cradle (made out of sacking material) to support the weight of the antenna was cut and sewn together to fit inside the table frame. Velcro was sewn on to cloth cradle and used to fix onto the table frame. This was done to allow for quick and convenient disassembly of the installation. The antenna was placed in the cradle so as to be in a central position parallel to the tabletop. The cable from the antenna was routed along the table frame and down the inner leg to the floor where it was linked to the coaxial cable from the tag-reader subsystem. The tabletop was then replaced to give the table its original appearance. The final configuration step was to switch on the projector and check the image remained in sharp focus on the tabletop surface, adjusting the mounting bracket, zoom and focus controls where necessary.

3.2.5 Artefacts

A small collection of household and personal artefacts were assembled for use with each *Habitat* station. RFID tags were concealed within or taped on the underside of these objects (figure 3.4). Since metal interferes with the ability of the antenna to read the tags it was important to avoid objects made of metal or containing electronics. Each RFID has an unique serial number determined at manufacture, which had been previously recorded in system database, therefore it was vital to attach the correct tag to each artefact. An image of each artefact was also supplied to the *Habitat* database.

3.3 Using Habitat

The method of interaction for *Habitat* was designed to be intuitive and natural. Users add and remove artefacts on a table as they go about their daily

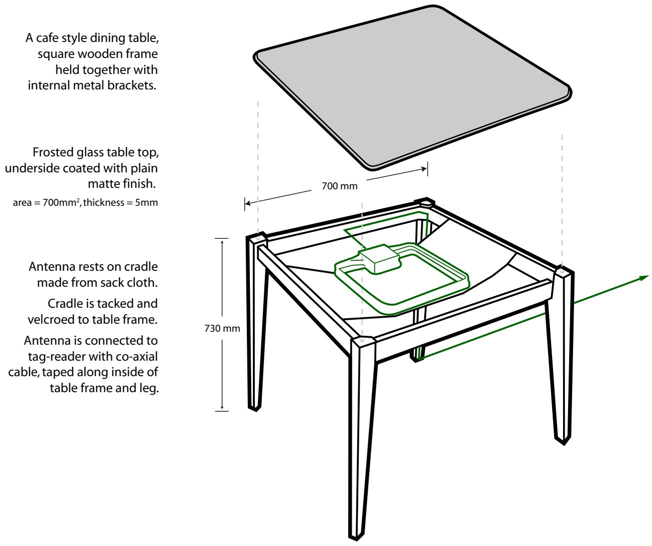

Figure 3.3: The Table with integrated Gate Antenna.

Figure 3.4: RFID transponder attached to underside of saucer.

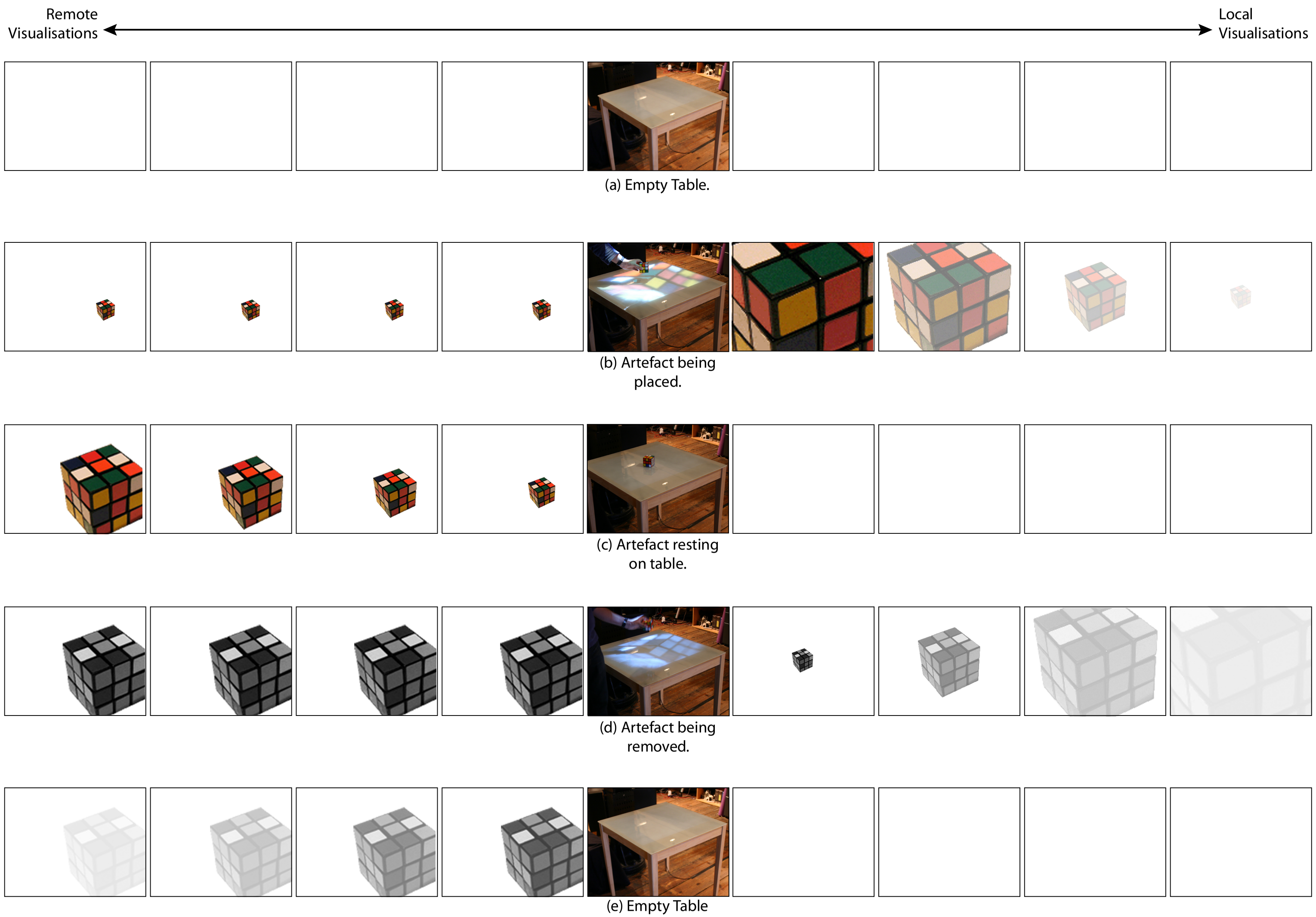

Figure 3.5: Interactions and their corresponding visualisations.

activities, thus unobtrusively participating in communication of awareness information. Figure 3.5 is a stem and leaf diagram that illustrates the interactions with *Habitat*. The ‘stem’, the images labelled (a) through to (e), shows the sequence of actions a user may take thus moving the system through various states. Following the sequence of pictures along a ‘leaf’, left (remote table) or right (local table), shows the animation of a visualisation with time.

(a) describes the situation when the system is idle and neither user is interacting, the tables are empty. Correspondingly the leaf pictures show no visualisation activity either on the local or remote tables.

(b) shows that when a user places an artefact onto the table visualisations are fired. The local visualisation displays animation of an image of that particular artefact ‘falling’ into the centre of the table. The first graphic shows the colour image at a large size filling the tabletop. As the visualisation progresses the image scales down rapidly whilst decreasing its opacity - thus fading out. Simultaneously, on the remote table a colour image of the artefact appears at a random location on the table surface.

(c) shows the artefact resting on the table. This creates no further visualisation on the local table. On the remote side, as time passes the image of the artefact slowly increases in size. This growth denotes an remote activity that is ongoing. To avoid obscuring the display, this image stops growing when its scale reaches a predetermined arbitrary size.

(d) shows that removing an artefact the user triggers further visualisations. The local feedback visualisation is in effect the reverse of the previous local feedback animation when the artefact was placed on the table. The image of the artefact begins small, fully opaque and greyscale in the centre of the local table. As the animation progresses the image becomes larger and less opaque, giving the effect of the image ‘floating’ up and out of the table. On the remote table, the image of the removed artefact changes from a colour image to greyscale. Slowly over time, the opacity of the greyscale image reduces to zero, causing the image to fade away completely. The state of the system is now as it was at the beginning.

3.4 Summary

Habitat, a novel, fully-functional prototype system was built as a solution to providing background awareness between people in long-distance relationships. There are several reasons that make this system a particularly practical solution to deploy and use as a test-bed awareness system.

Firstly, the materials and equipment required to assemble a *Habitat* station are easily obtainable, off-the-shelf items. Considerations such as size, power, safety and noise levels were in line with the expectations people have for appliances in the home. The networking connectivity to link two stations together is now fast becoming ubiquitous with the current trend in the take up of residential broadband.

Secondly, the proposed use, functionality and behaviour of the system was designed to be clear to end-users. Interaction with the system occurs solely through household artefacts. The system has been designed with care so as not to convey personal data or attempts impinge on users' privacy. Users are provided with a unambiguous, transparent metaphor to interact with the system as they wish. Interaction with the system is not mandatory and has been designed to support rather than displace any other form of communication between partners.

A final point is that *Habitat* was fully tested, stable, fully-functioning and ready for deployment. This is in contrast to some of the awareness-systems reviewed earlier, many of which were either design concepts with little functionality that could only be deployed for a limited time. *Habitat* is a robust, appliance-like solution that had been designed from the outset to be integrated into a home, effective for long-term deployments.

Chapter 4

Results

4.1 Development Context

Habitat was developed within the Human Connectedness group at *Media Lab Europe*[1] — a non-profit organisation committed to multi-disciplinary research, and the European research partner of the world-renowned *MIT Media Laboratory*.

The style of research fostered at the Media Lab is one focussed on the rapid development of prototypes or demonstrators. The general approach to developing projects is not constrained to one formal methodology but based on a combination of several forms at the individual researcher's discretion. Some have characterised the MIT Media Lab style as a philosophy of "Demo or Die," inspired by methodologies such as *Boehm's Model* and *Verplank's Spiral*[36, p15].

Taking inspiration from some of these ideas, *Habitat* was created incrementally in a series of prototyping phases (figure 4.1). Each phase of development resulted in a 'stand-alone' prototype that addressed particular facets of the problem and was frozen in order to be used as a demonstrator of the overall project concept. Naturally, the results from one phase acted as the starting point for the next phase of development. The completion of each phase would

[1] Media Lab Europe, Dublin, Ireland, closed in January 2005. Human Connectedness group website — http://www.medialabeurope.org/hc

move the project further out of the development spiral, thus toward the evolution of an increasingly functional solution.

In turn, each prototyping phase constituted of several iterations around a three component process — *design, develop* and *deploy* (figure 4.2). The *design* component takes an aspect of the problem and marries it with one of several solutions. An informal specification of the level of functionality expected from the prototype acts as the checkpoint to the completion of the phase. A prototype uses the design principles discussed earlier (see 1.3) as basic guidelines to work from together with feedback, insights and findings uncovered from previous phases. The *develop* stage is concerned with realising the design with the appropriate level of functionality in software or hardware to demonstrate the underlying concepts of the system. The *deploy* component of the prototyping exercise is concerned with "putting it out there" and covers a range of testing and reviewing of the demonstrator. Informal testing, feedback and review is carried out within research group meetings or amongst peers in critique sessions. Bugs, missing functionality and other short-comings highlighted during the informal deployments, result in further iterations around the development cycle until the prototype satisfies the requirements set for the phase and is ready for a more formal audience.

4.2 Deployment Context

The Media Lab model encourages informal visits by sponsors and research partners on a regular basis where the expectation is to demonstrate new research. The prototypes act as discussion points for the research and are shown at formal open days and sponsor visits, along with conferences and public exhibitions.

Habitat was regularly demonstrated at Media Lab Europe 'Open_House' events. These events took the form of an open day, occurring approximately monthly, giving current and prospective sponsors, members of academia and the press the opportunity to visit the laboratory and gain a snapshot of the research being carried out at the lab. The format of a Open_House event was a morning of keynote presentations centred around a specific research theme

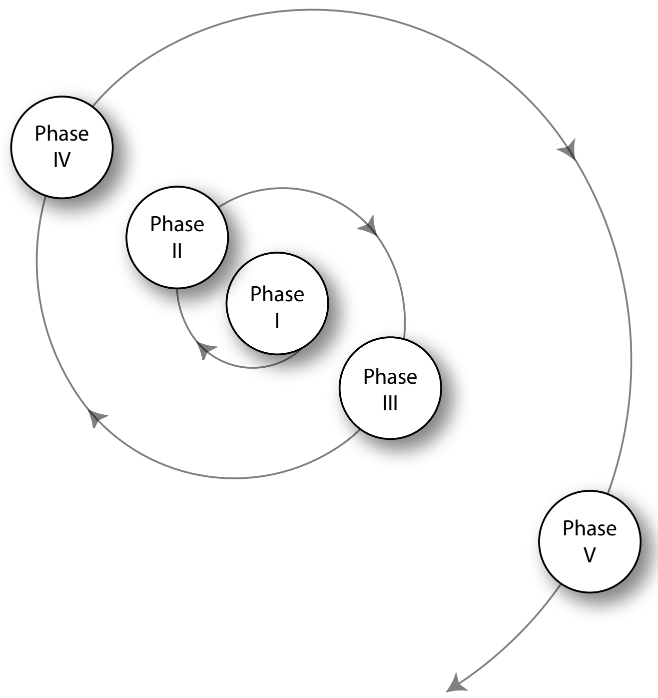

Figure 4.1: An overview of the prototyping phases

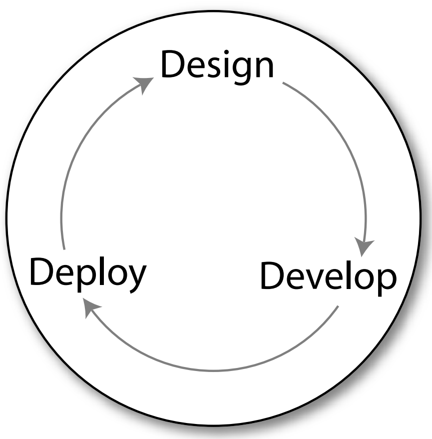

Figure 4.2: The process followed during a prototyping phase.

followed by the ‘open house’ in the afternoon, where the visitors are free to roam the lab and see the demonstrators and talk to the researchers. A typical event would attract anywhere from 75 to 300 people. Although it was impossible to have something completely new to show working each month - a stable version of the prototype at the end of each phase was frozen and demonstrated to visitors along with some discussion of the upcoming features in the next phases of development. This meant that regular visitors to the lab saw the progression of the ideas within *Habitat* over time. During the Open_House, small groups of visitors would gather around the system for a demonstration and informal presentation. On average visitors spent about fifteen minutes with the prototype where they asked questions and gave feedback on the research. From the start of the project in January to the final prototype of the system in October 2003, seven Open_House events were held. These events supplied a number of opportunities to test the *Habitat* concept out on non-researchers.

By far the most demanding deployment of *Habitat* was the exhibition at the 2003 E-Culture Fair. The event provided a showcase for research and development in the field of New Media to the general public, academics, businesses and government. The event is organised by Virtueel Platform, a network of Dutch media labs that advise the Dutch government on policy in the fields of digital media, technology and contemporary culture. The event attracted significant public exposure for *Habitat*.

4.3 Prototyping Stages

Habitat was not created in a single linear path, but as a series of prototypes. The solution described in this thesis to the problem of providing awareness over a distance started with many loose threads, as a series of hunches and ideas that evolved and came together over time. Following this path led to a number of sub-problems and issues that had to be tackled on the way to the eventual solution to the main problem. Described below is this journey of designing and developing prototypes, deploying installations, collecting results and feedback on the way to a final system.

4.3.1 Phase I of Prototyping

The development of *Habitat* began with a ‘hunch’ that using the physical elements of a home, such as architecture or furniture could be a suitable interface for conveying awareness between two people living apart. The aim of this phase was to develop a suitable design for this concept, setting in motion a series of quick experiments to see how this could work.

Previous work undertaken by the author (whilst at BT) on responsive sensing environments[2] and tangible interfaces[3] had already proven the scope of using RFID tagged objects as simple interaction with rich multimedia applications.

The central requirement of the solution was to provide awareness over a distance, therefore a decision had to be taken on the actual subject and format of this awareness. It was decided that the daily activities of each partner would be the subject of the awareness. Providing awareness of these activities would entail the of supply of images relating to these activities between the partners — for example sending an image of a book to denote reading.

A RFID tag was taped to the underneath of a coffee mug and placed in the field of the antenna (figure 4.3) of the tag-reader. The tag-reader was connected to the development computer and a program was written to identify the tagged object and display its image (figure 4.4). On taking the coffee mug out of proximity of the antenna, the image disappears. Having verified the functionality of this aspect of the prototype, the next task was to test if furniture was suitable for displaying the awareness information. The decision to use a table was straightforward since they provide a large flat area to project information on to and is a common element in most homes.

A basic table structure was constructed using a sheet of thick acrylic board placed on two height adjustable wooden trestles, all of which were found around the laboratory. A video projector was mounted overhead and connected up to the PC. The tag identification program was run and its output displayed on the table surface via the projector. The height of the overhead

[2] *Reflex* — a system for personalised wireless interaction [37].

[3] *Tagliatelly* — using physical artefacts with an interactive multimedia jukebox.

projector was adjusted and focused to fill the table's surface. One problem with this basic set-up was that the bright light of the projector made the dirt and scratches on the surface of the acrylic board highly visible. A plain off-white tablecloth was purchased to remedy this situation, producing a slightly muted matt surface to project onto (figure 4.5).

An attempt to integrate the tag-reader antenna under the surface of the table proved somewhat unsuccessful. This change would allow objects to be placed directly on the table-top for detection by the antenna hidden below. Although the antenna has sufficient power to read the tagged objects through the acrylic table-top, the weight of the antenna meant that it could not be mounted to the underside of the table-top reliably for prolonged periods.

The next development iteration focused on the software, extending the visualisations used in the demonstrator. Firstly, taking the 'having a coffee break' idea further, the image of the coffee mug was replaced by two images. On placing the mug on the table, the regular image of the coffee mug would appear. On removal of the mug, the image of mug was replaced with one of a 'coffee ring'. This was an attempt to provide a real-world analogy with leaving a mess behind, such as crumbs on a table or a coffee stain. Secondly, the visualisation of several further activities was added. Some new objects were tagged and unique images added to the software. Placing different objects on the table now resulted in the associated image appearing in a fixed location on the display (figure 4.6). The location of the image had to be pre-determined as more than one object could be placed on the table and identified by the system simultaneously. Having images all appear in the centre in this situation would cause them to occlude one another.

Findings from Phase I

The completed demonstrator was shown to fellow researchers to solicit feedback. It was felt that the prototype was a good first attempt and demonstrated the concept well and the underlying story was believable. Everyone agreed that the system was responsive enough, identifying objects quickly and reli-

Figure 4.3: A mug placed inside the antenna.

Figure 4.4: The visualised image of the mug.

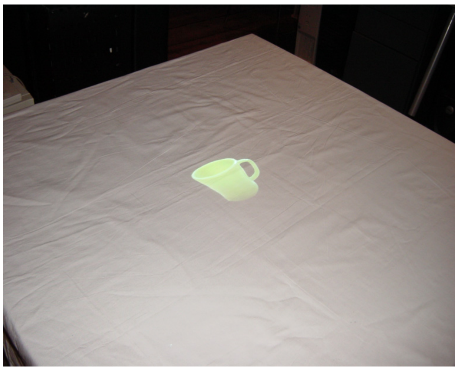

Figure 4.5: The mock-up table in the initial prototype.

Figure 4.6: The visualisation of multiple objects.

ably.

When the system was shown with the antenna hidden under the tabletop, some commented that the system was not actually conveying anything useful and defeated the point of the demonstration. In this situation, placing a mug on the table resulted in an image of the mug appearing in the centre of the table, which did not provide any new or useful information — since the observer could see the (real) physical mug on the table, the (virtual) image of the mug projected onto the table is redundant.

The aspect of visualisation that concerned the coffee stain image (on removal of the mug) had a mixed reception. Some did not recognise the image of the coffee ring and needed an explanation, others who did recognise the image commented that it was an interesting methodology but an image of a stain persisting indefinitely would annoy users who liked ‘neatness’ in their living space. A way around this could have been to incorporate animation into the visualisation, for example having the coffee ring fade away over time.

On the aspect of recognising multiple objects, feedback again was slightly negative. It was felt that the images shown for some of the objects were confusing. For instance, for the dinner plate an image of a group of people sitting around a table was displayed. This image was not readily associated with mealtime by many observers and indicated that better images needed to be chosen. The images used were mostly taken from a personal archive and therefore not meaningful or deemed too abstract by the researchers. Other comments were that by using fixed locations for the images, potential users may find the predictability a little tedious.

4.3.2 Phase II of Prototyping

The aim of the second phase of prototyping was to develop the networking aspect of the project. After having proved the viability of furniture as a medium for awareness in the first prototype it was important to move forward and illustrate the concept fully using two paired tables. The first demonstrator employed a mock-up of a table, quickly and crudely constructed out of spare materials found in the lab, which had now outlived its usefulness. Properly designed furniture was required for several reasons. It was desirable for the project to be aesthetically appealing since it was to be used as a public showcase for the research. Next, the properties of the material used for the tabletop had to be conducive to video projection. Lastly, the construction of the table needed to accommodate the tag-reading antenna.

It was thought that a pair of custom tables needed to be designed and hand built specifically for this project, using materials and equipment from the lab workshop. Although there were local experts with the necessary knowledge and expertise to help guide the construction effort to make up for the shortfall in the developers workshop skills, it was realised that the time and effort required to make the furniture far exceeded the cost of buying off-the-shelf items and making modifications. This made sense in relation to the overall goal of the project which aimed to use everyday typical furnishings for awareness. A brief search of a local furniture outlet yielded a suitable pair of tables (figure 4.7).

The tables were supplied flat-packed and required simple assembly. Conveniently, most demonstrations at the Open_House events are given in each research group's work area. This saved the hassle of having to move the tables around during development. The tables were put together and positioned a few meters apart from each other. The next task was to integrate the hardware subsystems together. The lab had a plentiful supply of computing hardware, video projectors and mounting brackets but the tag-reader was relatively specialised and expensive. There was to be a significant lead time in procuring the second tag-reader so this phase of prototyping had to go ahead with only one node that had the ability to sense tagged objects.

One key problem to solve was how best to integrate the antenna with the table so that items placed upon it were robustly detected. Due to the time constraints of an impending Open_House event it was decided to temporarily affix the antenna flush to the underside of the tabletop using strong adhesive tape until there was an opportunity to develop a permanent solution.

The next pressing target was to develop software that captured and conveyed the awareness information over the local network. The table with the tag-reading system used its computer as the primary client; the other table used its computer to act as the server and display images of the objects placed on the first table. The client computer polled the tag-reading hardware to identify any objects placed on the table, sending messages at regular intervals to the server, which in turn interpreted these messages and displayed the corresponding images.

Following criticisms of the quality of the images in the first prototype, a new approach was taken for images in this prototype. Rather than relying on images of objects taken off the Internet or from personal photo libraries, high-resolution photographs were taken of each of the actual artefacts used in the demonstrator. A digital camera was mounted on a tripod in a fixed orientation. In turn, each object was photographed on a plain black cloth. Af-

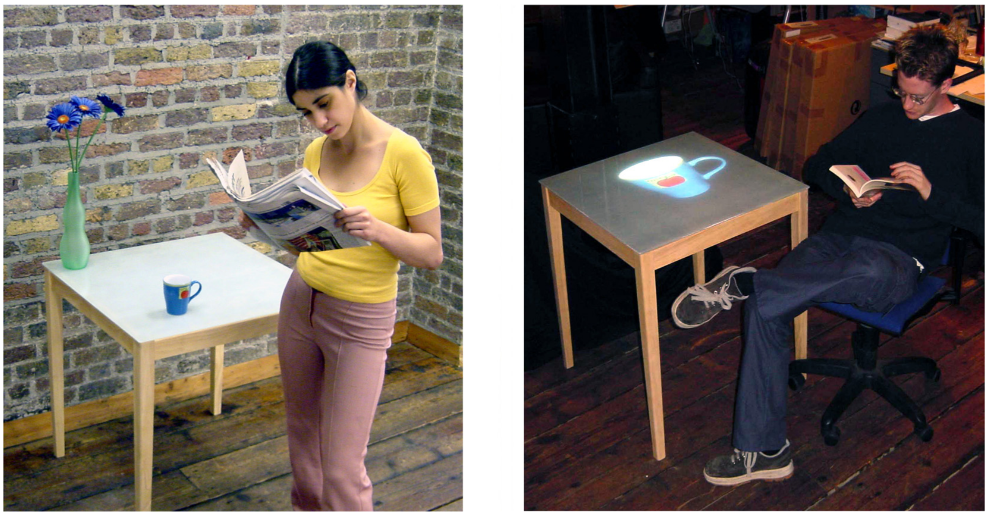

Figure 4.7: The two tables installed at Media Lab Europe.

ter capturing the images, they were downloaded to a computer for processing using image-manipulation software (Adobe Photoshop). The first step was to extract the image of the object from its background. The plain coloured background greatly simplified this task, leaving behind a clean crisp image of the object which was then placed on a transparent background (Figure 4.7, right-hand image. Please note that the vase on the table in the left-hand image is not tagged, therefore does not appear on the right-hand table). Each image was cropped and resized to the same dimensions (200 by 200 pixels). The transparency information in the image files allows the irregular shaped outlines of the objects to overlap. The final step was to replace the old image files on the system with the new copies.

Findings from Phase II

Overall the prototype was well received by visitors. The styling of the tables greatly added to the overall finish and presentation of the prototype. The appearance of the projected image floating on frosted glass tabletop gave an appealing 'look and feel' to the project. The batch of restyled photo-realistic images of the interaction artefacts was also added to this experience.

The lack of two tag-readers detracted from the full impact of the demonstrator, as people complained that they couldn't interact with both ends of the system and how one side of the table was 'blank'. The video-projector over the tag-reading table was redundant and kept switched off, as it had no images to display. This issue of the 'blank' table led to questions about how the users actually know the system is working at all. In the case of the lab demonstration, the paired table was at the other side of the lab and could be seen easily by the users, so they could check the system was working by glancing over to the remote table. This would not be the case in a real-world setting where the partners are living hundreds of miles apart.

4.3.3 Phase III of Prototyping

There were several goals for the third phase of prototyping. The foremost objective was to integrate the recently acquired 2nd tag-reader. The remaining efforts were to investigate the possibilities in providing visual animations of the awareness information.

On the surface, the incorporation of the second tag-reader into the system should not have posed any great difficulty, since the equipment was the same model and specification as the existing apparatus. However, due to the rapid development of the early prototypes, the underlying software architecture was not well organised and contained several inefficiencies and redundant elements left behind from exploring side-avenues or debugging routines. The networking and message-passing routines needed a thorough overall too, so it was decided to rewrite the software according to a more structured design taking into account the learning from the previous phases of development.

The new version reflected the fact that each table (station) was a complete mirror of the other, acting as both a client and a server, and therefore executed the exact same version of the code. The new software architecture separated the potentially 'slow' elements, such as the serial port access to the tag-reader and the networking routines where speed was not a priority from the elements of the code were speed sensitive and had to be 'fast', such as the graphical visualisations and animations.

The network routines were redesigned to be more reliable and efficient to address the shortcomings noted in the previous phase of prototyping. The software was redesigned to use TCP, a network protocol that attempts to guarantees delivery in most cases and ensures messages are assembled in sequence. The message-passing routines also needed to be rebuilt. The new solution was far more intelligent in its use of bandwidth, only transmitting information when a change occurred on the table and staying 'silent' when nothing was happening.

The awareness visualisation features also took a large step forward during the third phase. The first problem to tackle was to figure out how the visualisations could use a more intelligent use of the display space. The current technique of using arbitrarily chosen fixed locations for images (figure 4.6) was fine for a small number of items, but not suitable for a larger set of objects. It would be advantageous to be able to place images anywhere on the table-top. Several possibilities for placement algorithms were generated, eventually selecting a random placement algorithm. This in effect placed new images in a random location within the bounds of the display. This location was only fixed for the duration of the item being on the table, resulting in subsequent placements of the same item appearing in different locations.

Using the newly created images from the previous phase, several animations of the images were storyboarded to convey awareness information of the activities between the partners. Three interesting ideas for visualisations came out of the brainstorming. The visualisations created animations by applying transformations on the size, colour and opacity attributes of the still images. No video was used. Once again, due to pressing demonstration schedules, only one of the various visualisations was programmed during this stage.

On placement of an object, a fully opaque image of the object would appear on the remote table. Over time this image slowly increases in size, scaling up to a maximum factor of three times it original size. On removal of the object, the image stops growing in size and become grey-scale. Slowly the opacity of the image is be reduced to zero, giving the effect that it is fading away with time (figure 4.8).

Figure 4.8: The sequence of visualisations (clockwise from top-left).

Findings from Phase III

The demonstrator with two working networked nodes was becoming closer to a fully functional and complete system. The newly rewritten software architecture reaped many benefits, including making the system a more responsive than in the previous prototype. Since the tables were positioned close together, visitors who tried out the system had line of sight of both tables. This allowed them to easily assess the speed of response of sensing the objects at one table and the displaying of visualisations at the other table. Groups of visitors added and removed objects on both tables simultaneously without any apparent lags in performance of the system.

The animations of the images were also approved by peers. The random placement of the images was thought to be greatly sophisticated compared to the fixed locations used in the previous versions. Informal feedback was sought on whether people could understand the animated visualisation. The sequence of an image appearing, growing, turning grey and then fading away was thought to be particularly intuitive and easy to comprehend. Unusually, audiences did not come up with any substantial comments when asked how the visualisation could be improved. Some people were under the impression that the animation of the images were pre-made video clips being sent between the two nodes. They were surprised to learn how little bandwidth was used by the prototype since no images or video were being transmitted.

A small flaw was found with the method used to mount the antenna under the tabletop. The close mounting to table surface caused a silhouette of the antenna to be seen on the tabletop.

4.3.4 Phase IV of Prototyping

The objective during this stage of prototype was to tie-up several loose ends and follow up some creative ideas for extending the system's functionality. The immediate task at hand was to eliminate the highly visible silhouette of the antenna on the tabletop. Also the two remaining visualisations designed in the previous phase were yet to be implemented.

There were a number of design requirements for the solution to mounting the problem. It was no longer feasible to have the antenna mounted flush against the semi-opaque tabletop as the outline of the antenna would still remain visible. The antenna needed to be suspended far enough below the tabletop so it could not easily be seen through the top of the table, but not so low that it could be seen when looking at the table from a side view. These aesthetic requirements were necessary to maintain the illusion that it was just 'regular' furniture. The functional requirements were that the position of the antenna needed to be close enough to the table surface so that the distance did not adversely affect the range and reliability of reading the tagged objects placed on the tabletop. Another parameter affecting the method of mounting the antenna was its weight. The antenna is made of coils of thick coaxial cable and heavy iron-cores, encased in a ruggedised casing, weighing around a kilogram.

The solution was finally overcome with the help of a vacation placement student[4] whilst collaborating on a related project[5]. Her solution was to con-

[4] Aoife Ní Mhóráin, Royal College of Art.

[5] *Aura* — an intimate remote awareness system based on sleep patterns. Aoife Ní Mhóráin,

struct a cradle for the antenna that hung inside the table frame. The glass table top conveniently lifted to allow access to the inside of the table. Velcro was sewn onto two edges of rectangular piece of stiff sacking material, slightly longer than the width of the table. Adhesive Velcro was tacked to the inside of the table frame which mated with the Velcro on the cradle. The thick black coaxial cable from the antenna was taped to the inside of a table leg down to the floor using beige coloured masking tape to help conceal it. With the physical aspects of the demonstrator complete, the visualisation features of the system could be further developed.

Two visualisations designed earlier were yet to be implemented. Both visualisations used the same random placement algorithm developed in the last phase. The first of these was as follows. On placing an object on the table, a full colour, fully opaque image would appear at a random position on the remote table, slowly growing in size from zero to a maximum scale of 3 times the size of the original image. On removal of the object, the exact reverse would occur and the image would slowly shrink away to nothing.

The next remote visualisation was as follows. On placing and object on the table, a full colour image would fade in at a remote position on the remote table. The size of the object was kept constant and the opacity was increased from zero to one (denoting a fully opaque image). On removal of the artefact, the exact reverse happened and the image opacity was reduced to zero, giving the effect of fading away.

The next major leap forward in the functionality came from the concept of local feedback. The idea of local feedback was developed after realising a solution to the 'blank' table problem (mentioned earlier) would be critical factor in the usability of *Habitat*. The importance of local feedback had not been realised during the prototyping up to this point. This was because the physical arrangement of the furniture in the development environment and during demonstrations was already providing a sense of feedback. This had unwittingly hindered proper consideration in the designing the user interactions. With the tables placed within line of sight of one another, it was usually possible to see remote visualisations from the table that was being interacted

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Dipak Patel and Stefan Agamanolis.

with. This was a oversight — in a real-life deployment the tables would be geographically separated.

In order to simulate a more realistic scenario, one of the tables was moved away from its regular position to another part of the lab so it was no longer with in eye-fall of the other table. Naturally it became immediately obvious that someone living with a *Habitat* system could have no idea whether the system was actually working or not. This situation would most likely arise when the remote user does not place any objects on their table, hence the local table would be 'blank'. Since there is no direct feedback, the local user may inadvertently forget that the furniture was 'live'. Placing tagged-objects on the table would result in messages being sent over the network by the seemingly unaware local user. The notion of being able to 'accidentally' transmit information about personal activities is a considerable privacy issue and one that could detract from the eventual real-world use and deployments of *Habitat*.

A few ideas were initially brainstormed and quickly prototyped to see if they were suitable for visualising local feedback. The first was to create a 'flash' effect. On placing an object on the table, the table would briefly turn white - creating a 'camera flash' style effect. The same flash would occur when the object was removed. This solution had the drawback of being far too bright and visually distracting - much like a real life camera flash.

The next visualisation to be examined was one of a 'radar-sweep'. In this scenario, each time a tagged object was read on the table, a thin green line would perform a radial sweep around the table, similar to that of a radar display. Removing the object repeated the effect. This idea was quickly dropped since the underlying metaphor was flawed. Actual radar terminals have a line constantly sweeping around their displays. This visualisation only displays a sweeping line when an object is added or removed. Additionally, some users sensitive to privacy concerns may think this visualisation is 'scanning them'. Although people are used to having things scanned in certain locations (supermarkets, airports) this idea maybe unpalatable in the home By explicitly visualising this 'scanning' may unnecessarily agitate ill feelings toward the system. For these reasons this idea was dropped.

Figure 4.9: Testing the local feedback visualisation

The final design for the local feedback visualisation took the metaphor of objects falling in and out of a table — akin to the notion of depth when throwing a penny into a well or taking something out of a large barrel. On placing an item on the table, the system projects a large size, full colour, full opacity image of the object over the centre of the display (figure 4.9). Simultaneously, the image is quickly scaled down to zero and its opacity is reduced to zero. The composite effect of the image shrinking and fading away, appears as if the object is falling through the table. On taking the object off the table, the system projects a small size, grey-scale, full opacity image of the object in the centre of the display. Simultaneously, the image is scaled up from zero to a large size and its opacity reduced to zero. The composite effect is one of the image being lifted out of the table. Detailed images of the local feedback visualisation are in the Method Chapter.

Findings from Phase IV

Responses gathered from a group critique of the prototype were very positive about the addition of the local feedback functionality. It was felt that it seemed an elegant and natural extension to the overall interaction concept. However, the two new remote visualisations were not preferred when compared with the visualisation created in the previous iteration of the system. People said that with the newer visualisations it was difficult to see when an object was actually removed — the point at which the object began to fade out or shrink was ambiguous. In contrast the change from a full colour image to a greyscale image in the original visualisation was a clear sign that the object had been removed. The use of the same colour metaphors (full colour for added objects, grey-scale for removed objects) in the remote and local visualisations reinforced the entire interaction metaphor, aiding the users in understanding of what was going on.

Some people commented that the demonstrator could use a larger variety of objects. The system was being demonstrated with a few tagged objects at each table. Questions had been raised by visitors on what kinds of objects could be tagged. Having more objects would address some of these questions and also provide a stronger graphical impact when visualised on the table. During the Open_House many visitors who were not familiar with RFID technology asked how the system worked in detecting the objects. When the table-top was lifted up to show the integrated antenna mounted on the cradle, many delegates commented were surprised with the simplicity and elegant of the solution.

4.3.5 Phase V of Prototyping

The E-Culture Fair 2003 was held in Amsterdam, spread over three central locations, on 23rd and 24th October. Over 2,000 thousand visitors, ranging from members of the public, students, artists, technologists, journalists and government ministers had the opportunity to see 50 projects. The projects were sourced internationally and organised in a number of themes, each project illustrating what new technologies may mean for future work, communication, education and play. *Habitat* was included as part of the 'Mobile Home' theme. This category presented projects that explore the emotional and relational effects of mobility, global communication and awareness of place and location. Initial contact with the E-Culture fair had began when the exhibition organisers saw a demonstration of an early version of *Habitat* prototype during an Open_House event.

Due to budgetary issues, transporting the whole *Habitat* installation from Dublin was not possible. It was decided that the event organisers would hire video projection systems and source suitable furniture in Belgium and have it shipped to Amsterdam, whilst we would complete work on the software and bring over a pair of tag-readers and laptop computers to run the system on. Although the development so far had taken place on full size desktop computers it was obvious that they could be replaced with smaller and lighter laptop equivalents to ease the travel over to the event.

The computing platform on which *Habitat* was developed on to this point was standard x86 hardware with the Linux operating system running the Isis programming environment, as described in the method chapter. The organisers were not able to provide computer hardware at the event, and shipping large computer workstations would be costly. Using Laptops would be a much better solution but the only pair of machines available at short notice ran the Mac OS X platform. Fortunately, parallel work by the developer of the Isis programming language, had begun a port of Isis to the Mac OS X platform. This experimental branch of Isis was stable and complete enough to support all the functionality required by *Habitat*. At this point the entire development effort shifted over to the new platform as it required as much testing as possible before the exhibition. The previous code was transferred over to the two laptops. A small modification to the system components was required, since these laptops did not have RS232 serial ports required to interface with tag-reading systems. Sets of USB to RS232 dongles were used to connect each laptop to a tag-reader. Small modifications in the tag-reading software libraries were made to enable support for the USB-RS232 devices, but otherwise the operation of the dongles was transparent to the rest of the system.

Once this stage of development of reached, the physical aspects the installation was dealt with. It was decided to keep with the look and feel of the furniture deployed in Dublin, since the size, height and quality of projection on the frosted glass were known to work well and met the requirements of the

Figure 4.10: Objects waiting to be used on the plinth.

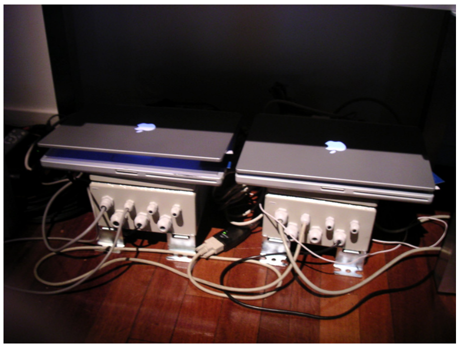


Figure 4.11: Laptops and tag-reader hardware under the plinth.

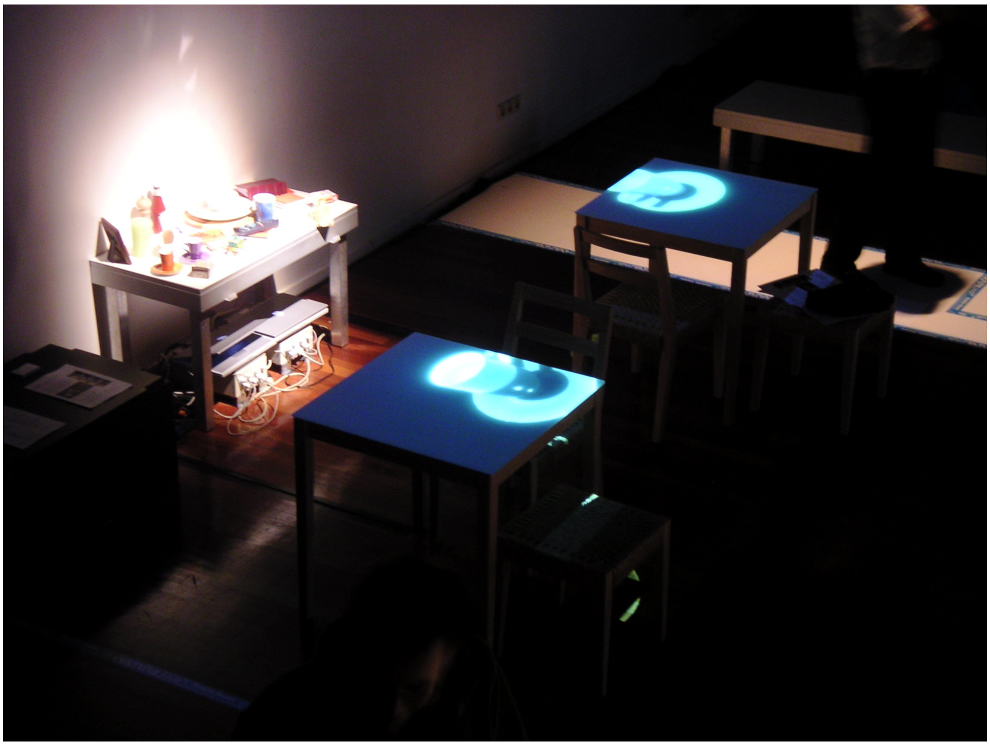


Figure 4.12: An overview of the installation.

exhibition space allocated to *Habitat*. It was considered better to change as little as possible of the physical elements of the installation at that point. Since the *E-Culture fair* was to be a far longer running event than the demonstrations in Dublin, which rarely required the system to be running for more than 3 hours, it was decided that having somewhere to sit by the tables would be a natural and useful step. A set of identical tables to the ones used in Media Lab Europe *Habitat* installation were sourced at a store in Antwerp, along with a pair of matching chairs and stools, to be delivered directly to the exhibition venue.

Once all the physical aspects of putting together the installation were done and tested in Dublin, focus returned to the software development. It was decided the third visualisation discussed earlier was the one that was most visually appealing. Since the exhibition would require *Habitat* to stand alone in a gallery setting, without any direct explanation or demonstration, it was likely that visitors may be coming and interacting with the exhibit over long periods of time. It was decided that the rate of change in the visualisations should be altered, so the scaling and fading effects were much slower. This decision was taken to pre-empt the fact that the installation may be observed for much longer period that during the more brisk Open_House demonstrations. These small changes were completed just in time to dismantle the system and head to Amsterdam.

Habitat was exhibited alongside several other projects in the Melkweg, an old theatre in central Amsterdam. Access to the venue was not available until a day before the opening of the exhibition, so all the set up, final testing and any tweaks had to be complete by then. After arriving early on the set up day to meet with the organisers, find the furniture and unpack all the components, the furniture was quickly assembled. The antenna cradles used were taken from the Dublin installation. The video projection system was not due to arrive until the morning of the exhibition opening-day, so that aspect could not be immediately tested. Luckily, the built-in screens of the laptops were able be used to test the software without the need for the projectors.

In the area for the exhibit, the two tables were placed approximately 1.5 metres apart. A chair and stool were paired with each table, allowing enough space for the visitors to flow around the installation. After initial testing was successful, as previously noted from earlier feedback, it was felt that the initial set of items for the table were lacking both in number and style for the event. Although only four or five items could be placed on the table without cluttering the table top and obscuring the visualisation - it was felt that it would be desirable to have a greater selection of objects that the visitors could pick and choose from.

In order to acquire the extra objects, a quick trip was made over to a local market, resulting in 20 new objects. These items were taken back to The Melkweg, where a digital camera was used as previously described to capture the images for use with in the system. The next stage in incorporating the newly acquired objects into the system was to tag the objects. Fortunately, enough spare tags had been brought over to attach to the all the new objects. Using adhesive tape a tag was placed under or inside each object. A utility program written during the initial phase of prototyping was used to provide an inventory of tag serial numbers when placed on the table. Each newly tagged object was placed in turn on the table and the program outputted the serial number. Finally the simple database in the *Habitat* system software which associates tag serial numbers to the images was amended with these new serial numbers, so that each object displayed the correct image upon identification.

A long plinth (figure 4.10) was set up to the rear of the *Habitat* installation to keep the extra objects whilst they were not being used in the demonstration. After testing the system with these new objects successfully, the area around the installation was tidied up and the objects placed ready on the staging table. Underneath this table were stowed the two tag reading systems and laptops (figure 4.11). A plain black cloth was placed over the table to conceal the system hardware beneath.

On the day of the event the contractors arrived with the video projectors. Although the organisers were aware of the requirements for *Habitat*, the height of the Melkweg ceiling and the limit to how low the projectors could be moved on the supplied mounts meant that the image projected onto the table was larger than the area of the tabletop. This meant that in operation, the system would place images off the table surface, or during the animation of the visualisations would grow in size and 'spill' over the edges of the table.

This was a significant problem and would have a big impact on the success of the installation. Since the projector height could not be adjusted or the focal length of the lens changed, it was decided to attempt to solve the problem in software. A quick fix was applied by changing the image placement section of the *Habitat* code. The random-placement code was changed to constrain the placement of the images within a rectangular border, which mostly masked off the area of the projected image that fell off the table top surface. Since the background of the *Habitat* visualisation was black, nothing would be projected in the 'dead' areas of the display. The width and height of the border was defined approximately by trial and error and not an exact mapping. Having solved this problem, the *Habitat* installation was ready for exhibition (figure 4.12).

Findings from Phase V

The exhibition ran for two consecutive days, attracting over two thousand people. The *Habitat* installation was successfully demonstrated and in constant use throughout the event(figures 4.17 and 4.18). During break sessions the system software was restarted, even though the installation for the most part ran without problem. Although the system could now be considered a deployed installation rather than a prototype, there were occasional glitches. For instance, interference affected the antenna when visitors placed metallic objects on the table or placed all the objects on the table at once.

Many interesting conversations with were had during the demonstrations and the feedback was extremely positive. The concept of this form of awareness over a distance was new to many visitors and many identified with the problem scenarios. The event was a good networking opportunity as it drew together a number of researchers from across Europe, some of which were also working the field of ambient technology. An interview for Dutch Television was given during the event and a story covering *Habitat* appeared in a leading Dutch national newspaper.

Figure 4.13: Right-most table - note images of objects on left-most table (below).

Figure 4.14: Left-most table - note images of objects on right-most table (above).

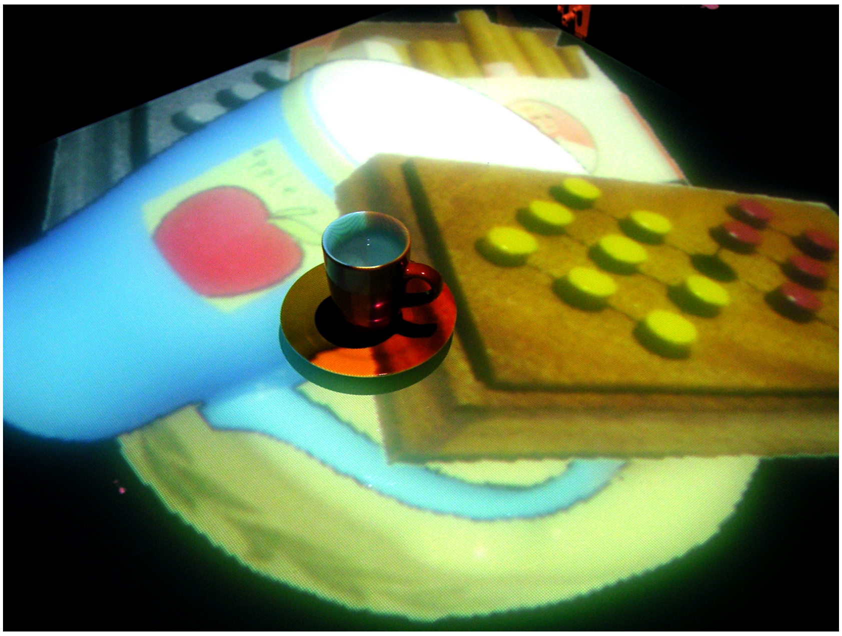


Figure 4.15: Close-up of right-most table

Figure 4.16: Close-up of left-most table

Figure 4.17: People receiving a demonstration of *Habitat*.

Figure 4.18: Hundreds of members of the general public interacted with *Habitat* during the E-Culture Fair.

4.4 Summary

This chapter has provided an account of the incremental development of *Habitat* through a series of prototypes. Detailed descriptions of the development activities are presented before a discussion of findings during testing and deployment of each stage of the demonstrator.

Chapter 5

Discussion

This research aimed to create a novel solution to the problem of providing awareness to people in long distance relationships. It was proposed that people involved in such relationships could use everyday items of furniture as an interface to an awareness communication system. In order to determine the feasibility of this proposal, *Habitat*, a prototype awareness communication system was developed. The prototype system linked together a pair of tables to unobtrusively record and display the activities of two remote partners. The implicit absorption of this activity information was expected to help foster a background awareness and greater sense of connectedness between the partners.

This chapter presents a review and detailed discussion of the findings reported in the previous chapter. The evolution of the prototypes was led by a series of design decisions. These choices were made with a balance of concerns between aesthetics and utility. The following discussion aims to substantiate the directions taken during the development of *Habitat*.

5.1 Physical Representation

Habitat was designed to employ a Tangible User Interface (TUI), a genre of interactive systems introduced earlier in Chapter 2. An important distinction exists between a TUI when compared with the traditional graphical user interface (GUI). The interaction model underpinning a GUI specifies a clear separation between digital representation (the graphical output on the screen) and its control mechanisms (the mouse and keyboard). The interaction model underpinning a TUI tightly couples its digital representation with a corresponding physical representation that acts as its control mechanism. The physical representations and control elements in a TUI usually take the form of interaction artefacts that the user is free to manipulate within the context of an installation. The design and selection of appropriate physical representations is an important aspect of tangible interface design, encompassing disciplines such as architecture, ergonomics, industrial and environmental design.

5.1.1 The Artefacts

Artefacts that are imbued with an implicit significance to the underlying information modelled by a system make good choices for its tangible interface. Previous TUI work has highlighted two approaches in designing the form of these interaction artefacts. One approach is to create custom artefacts that represent abstract concepts within an application domain. For instance a battlefield simulation TUI may use flag shaped blocks to represent captured territories. A second approach is to use 'found objects', pre-existing items that can be appropriated to represent specific actions in an application.

The physical representations used in *Habitat* take the form of commonplace objects that may be found in a typical home. The artefacts are coupled to the underlying activity information maintained by the system. Adding or removing artefacts from the tables results in a natural and intuitive interaction mechanism to control the exchange of activity information between the partners. The items were carefully chosen to embody a specific activity. For example a book (artefact) was used to represent reading (activity).

In addition, the physical states of the artefacts partially embody the digital state of the system. The user can inspect the items placed on their table to determine what is being visualised on their remote partner's table. The human readable nature of this digital state can only be said to be partial, since a user cannot determine extraneous information by inspection alone. For instance, whether an artefact has been removed from the table recently.

The technical realisation of binding the physical representation to the digital representation in a tangible interface is enabled through the control (user interaction) mechanism. The function of the control mechanism employed in a tangible interface often has an impact on the form of its artefacts. In terms of a control device artefacts can have a number of roles and meanings, acting as actuators, switches, dials, tokens, containers and tools. A tangible interface achieves control by sensing the state of artefacts, the manner of which is dependant the specific nature of the application. The sensing maybe done passively, for instance a camera placed overhead to identify artefacts by their shape. Alternatively the artefacts may be augmented with technology that actively relays its state, for instance an wind direction artefact that contains a dial that the user can manipulate.

The technology used for detection and identification of artefacts placed on a table was RFID. A small, thin and flexible RFID transponder was attached to each object. This control mechanism provides a reliable means of detection, as the antenna embedded in the tabletop will sense each artefact's transponder when placed on the table. Each transponder has a unique identification serial number; additionally many transponders can be read simultaneously.

The identification method used in *Habitat* is largely independent of the physical attributes of the artefacts, such as weight, colour, shape or density. This allows for a great deal of freedom in the characteristics of objects, including the ability to use objects that look the same. The main limitation of using RFID technology is that metal disrupts the ability of the antenna to detect transponders. As detailed in the Chapter 3, the materials for the table and the artefacts were chosen to minimise the amount of metal placed in the radio field of the antenna.

Another potential restriction is the use of artefacts containing electronics. This is because electromagnetic fields induce currents in wires. Placing an electronic circuit in a radio field may cause it to malfunction. Although some consumer electronics goods are insulated and shielded against this kind of interference, it is recommended to err on the side of caution. This problem was experienced first hand, a TV remote control used as a RFID-tagged artefact was rendered inoperable after prolonged use in *Habitat*.

In practise it was found that the ergonomic features about the artefacts were particularly important; the ease of grasping, manipulating and otherwise handling the objects during interactions. In an early prototype, one of the artefacts was an old concert ticket. In use the ticket, which took the form of a thin piece of paper was very difficult to pick up. Users often resorted to sliding it off the table. Occasionally, in between interactions the ticket would be blown off the table by a draft or a person brushing past the table. It was decided to opt for more robust, solid and graspable items of a certain weight such as a coffee mug when selecting the artefacts in the final prototype.

Aside from the physical representation, the logical role of the of the artefacts were also considered. The primary purpose of the artefacts was to communicate that a user was undertaking a certain activity, such as eating. Also considered were using certain artefacts to act as mementoes or keepsakes. People often collect objects to remind them of memorable events or their loved ones. Examples of such objects could be the aforementioned concert ticket or a family photograph. The role of a keepsake artefact could be used to convey that one partner is thinking about the other partner or other fond memory. It was thought that this may lead to sharing feelings of closeness and intimacy. Another role for objects that could have been explored was 'quick message' artefacts. These would be used to convey a simple note such as 'call me now'. Feedback received during later stages of prototyping suggested that a larger set of objects would have been better. To simplify early testing, only five objects had been incorporated into the system. For the final prototype deployed at the E-Culture Fair twenty objects were used, increasing the choice and variety.

5.1.2 The Installation

The artefacts are the main actors of the *Habitat* interface, but they rely on the rest of the installation to provide a context and stage for the interaction. The development of the prototypes moved from a trestle table mock-up to a matching pair of tables with integrated antennas.

The furniture used in the lab installation was standalone and did not have to ‘compete’ aesthetically with any other furnishings, as would be the case in a real home. A choice was made make the furniture as clean, plain and simple as possible, without sacrificing quality. Using tables that appeared shoddy or cheap would detract from the impression given by *Habitat*. The aesthetic of being ordinary and utilitarian, rather than extravagant would add to the impression that these were unmodified tables, just like any other piece of furniture in the home. By selecting a neutral design there is a greater chance that the tables could be easily incorporated into any household. Of course taste is a subjective matter. Choosing simple furniture helped to make our deployments more portable and quick to assemble. It was decided to use the exact same tables to form a pair, rather than using different sizes, form factors and tabletop shapes to reduce complexity of the development.

In terms of suitability for video projection, the tables procured for the installations performed well. The frosted glass tabletops were semi-opaque with a matt underside that helped the glass reflect some of the light back to create a bright clear image. Due to the flat-pack assembly nature of the tables, the tabletop was easily removed. It could have been possible to substitute the supplied frosted glass tabletop with one of a different material. The tabletop had to be fairly thin to allow the artefacts to be read easily. Metal could not be used, as it would shield the antenna’s radio field. Using completely translucent glass would cause the image to shine right through the table, rendering the visualisation invisible. In this case the antenna mounted underneath the tabletop would be clearly visible. Using mirrored glass would have reflected the image right back to the projector and also made the visualisation invisible. A thin table-top made out of plastic or wood may have been suitable to hide the antenna. This option was not explored as it was thought that a dull matt surface would absorb too much light making the visualisations appear too dim.

The opacity of the frosted glass tabletop caused a problem in the third phase of prototyping, where the antenna casing became visible through the tabletop. The mounting of the antennae up until that point had been temporarily fixed to the underside of the tables with gaffer tape. The intensity of the light from the projector shining down onto the semi-opaque glass resulted in the thick black casing of the antenna mounted underneath to be visible through the tabletop. The issue had gone unnoticed during the previous phases, since there was only one station that was able to display the remote visualisations and only one tag-reader. The non-visualising table had the antenna integrated inside it, and the projector over was kept switched off since it was not visualising anything. The problem was somewhat reduced by putting both the projectors into 'economy mode', where the intensity of the light is reduced to extend lamp life. Although the antenna frames were still visible, it was decided that this should be the default mode for the projectors since the reduced glare on the glass surface of the table made the visualisation less demanding on the eye.

The display technology used for *Habitat* was overhead video projection. The disadvantage to this arrangement is that a user can occlude the visualisation when standing over the table. Rear projection was not an option since a silhouette of the antenna mounted underneath the tabletop would be visible. There are other display technologies, such as LCD or plasma flat panel displays that could have been used to form the actual tabletop itself. Again having dense electronics in the field of the antenna would cause some problems.

5.2 Digital Representation

The digital representation in *Habitat* is the visual display of graphical information on the table surface. This form of representation by its very nature is the intangible, non-graspable element of a tangible interface. Each person views the digital representation of their remote partner's activities. This information is conveyed as a visualisation, compositing and animating a specific image to portray a specific activity, such as an image of a book to denote reading. The design ethics behind the visual aspects of *Habitat* are tensions between aesthetics, functionality and legibility.

5.2.1 Image Style

The images used to represent the remote activities underwent a number of changes through the early stages of prototyping. The main requirements for the images centred on comprehension and legibility. Designing the images to maximise these two qualities was a significant challenge.

Initially little effort was made to couple the digital representation to the physical representation, the images to the artefacts. The first prototype linked a coffee mug object to an image of a coffee mug found from the Internet. The image only bore a passing resemblance to the real object (they were both green). As further objects were added to the prototype, it became more difficult to find suitable images for use. Some experimentation was done by attaching images from a personal photo archive to objects. For example the dinner plate was linked to an image of people sitting around a table. This type of image received a lot of negative feedback during testing, the majority of people commenting that the relevance of some of the photographs used was difficult to understand or too vague. It was obvious that specific, unambiguous images were required for each artefact.

The form that these images should take was carefully considered. A balance between abstract and concrete representations was needed. A more abstract symbolic representation would have been to use words instead of images. A quick experiment was done to test this scenario. Each time an object was placed on the able, a text label would appear on the remote visualisation. This was rejected as a poor choice. Aesthetically it was unappealing. Legibility was poor, the words were hard to read when looking at the table from a distance. Reading upside down text from a skewed orientation was even harder. Although words are generally less ambiguous than images, comprehension is not guaranteed. For instance non-English speakers and young children may not be able to understand this type of visualisation.

The next form of image considered was iconic images, which capture the visual characteristics of the artefact. Several simple icons were created and deployed as visualisations. These icons fared well, being legible and comprehendible. Since graphic design was not a forte of the developers, the overall visual quality was low, the icons being bland and lacking realism. Symbolic images that associated a seemingly arbitrary scene to an object had already been examined. These types of image were open to interpretation and thought to be useful for keepsake style objects that were to be used to invoke a shared memory that the partners have for a certain event or situation. Performing this interpretation may require more effort on the part of the user, compared to when viewing a simple icon of a coffee mug. A low detail symbol maybe too ambiguous for a casual user to understand whereas using a highly detailed image of an activity being undertaken may be misinterpreted. For instance a photograph of someone reading a newspaper in a laundrette could be interpreted as someone either reading a newspaper, doing their laundry or both.

In the end it was decided to take a middle ground and use concrete iconic images of each specific artefact. The images were created by taking high-resolution digital colour photographs of the artefacts. This created a realistic image that was legible from a distance. The images were symbolic to a certain extent by virtue of the fact that no activity was being visualised, just the image of the object used in the activity. Users could interpret these images using their own knowledge of their partners behaviour. For example, if it usual for a partner to listen to music while studying, one may assume that an image of a CD case on the table means that they are busy studying.

5.2.2 Image Placement

After the first stage of prototyping where a simple image respectively appeared or disappeared on placing or removing a tagged object on the table, it was obvious that a strategy was needed for determining where to place images in the visualisation. Initially during an early version of visualisation, images were placed in the centre of the display. A scheme where images were placed in the centre was chosen since it allowed for greater clarity at a distance and allowed the images to scale to a maximum size without being cropped by the limits of the edges of the table. The main disadvantage of using a scheme of central placement used here was that subsequent images occluded older images, in effect only allowing the visualisation of one activity at a time, and providing no historical record of previous activities.

For the first demonstration of the prototype, a scheme where a number of fixed locations for image placement was used. The first image appeared in the centre of the visualisation, with subsequent images appearing in each corner of the display. This arrangement limited the number of objects to five, as the location of each image was 'hard-coded' into the system. Feedback from the demonstrator confirmed that using fixed locations for image placements was a poor choice. This placement scheme limited scalability, the ability to visualise more than five items concurrently. Also the predictability and repetition of the locations for the visualisations may cause users to be bored. This last point was subtle but important: a predictable and uninteresting visualisation may greatly affect the ability of users to pay adequate attention to the awareness information. If users find the display predictable, over time they may become overly familiarised with the various fixed configurations of images. This lack of visual interest may cause them to take longer to notice when new information is presented. There is also a chance they may subconsciously not see the visualisations; human perception tends to ignore static information.

It was concluded that a fixed image placement scheme needed to be replaced with a dynamic one. One idea explored was a scheme where the most recent interaction would appear in the prominent central position, with the previous interaction images shrinking to a smaller size and moving to the edge of the table. To implement this image placement scheme would mean that when a new interaction occurred, the display would have to be redrawn with new positions for all the existing images. This idea was not followed up for several reasons. Firstly it would be disconcerting for the user to observe the images changing positions between glances, when the images suddenly 'jumped' to their new positions. Moving all the images to new locations each time a new interaction occurred would interfere with the user's ability to build a mental model of what is 'on' the table in their short-term memory.

The solution used in the final version of the *Habitat* was to use random placement for the images. Using built-in pseudo-random number generator functions provided by the programming environment it was possible to calculate dynamically a position for each new image when it was added to the visualisation. The calculation of the position of the image took into account the boundaries of the display and the size of the image so that the image was never placed too far out of view. As each image was placed randomly, the monotony of a predictable display was avoided. Additionally the visualisation could accommodate more images, since they were fixed to a pre-determined grid. Naturally there was some overlap in the images as they appeared over time, but a low probability of any two images being placed at the exact same spot and occluding each other completely. A montage effect of images being placed close to each other or overlapping was easily achieved since the images had a transparent background.

The *Habitat* installation at the E-culture fair proved problematic with regard to the projected display. The projector could not be mounted low enough; this resulted in a larger projected image than desired. The visualisations spilled out of the area constrained by the tabletops. The system software was amended to provide a fix; the image placement module was altered to place images over a smaller area. This restricted the visualisation from appearing off the display area.

5.2.3 Animations

Ideas for using animated visualisation had formed from the beginning of the project, stemming from the concept of a 'digital wake', the desire to leave behind a trace to denote past activity. A digital wake is similar to a physical wake, for instance the water foam left in the ocean after the passing of a ship — a hint that something had passed by earlier. Adapting this to the visualisation of someone having a coffee break, it was proposed that on removing the coffee mug, the image of the mug would be replaced with an image of a coffee-ring stain. This idea seemed to make sense as physical coffee mugs leave stains on a table so maybe a digital coffee mug should leave a mark too, a pointer that someone had been there earlier. The 'removal image' acts as the digital wake, giving the users a chance to reflect on past activity. At that point, images appeared and disappeared in an instant, when artefacts were added and removed from the remote table. Without a removal image being visualised it was possible that a user may miss their remote partner's activity altogether if they are not looking at the table while the activity is taking place.

An image of a coffee-ring was also found from an Internet search and incorporated into the prototype. When the coffee mug was removed from the table, the mug image was replaced with an image of the coffee-ring stain. The flipping between the two images was the most basic of animations. The digital wake idea in this form fared badly with testers. The main reason cited that only the coffee-mug had a removal image associated with it. The images for the other artefacts did not leave a trace and just disappeared. This inconsistency was bad design. In reality the lack of removal images was not due to an oversight, but due to the difficulty in determining an appropriate image to show the cessation of each activity. In many cases such an image simply did not exist. For many activities, such as watching television, an easily identifiable trace is not left behind. This limited the usefulness of using removal images and another form of indicating the end of an activity. This result also underlined the earlier finding that representing activities (or the end of an activity) is problematic and it is better to represent the artefact used in an activity instead.

In due course, three complex animated visualisations were developed to denote activity information. Two of the visualisations were unsuccessful since they did not clearly indicate points when changes of state occurred. The moment when the image begins to fade out or shrink was hard to perceive, since these image properties were being used to indicate changes in remote activity, the visualisation lacked clarity. In contrast the original animated visualisation used a change of colour to indicate a removed artefact. The sudden change of a large full colour image to a grey-scale image was a clear sign of a change in state. Grey-scale was chosen to denote a 'dead' object.

5.2.4 Local User Feedback

A significant addition to *Habitat* was the concept of providing local feedback. This idea came during the final phase of development, after the key visualisation behaviour had been implemented. The two tables used in the lab environment were in close proximity, a few metres apart, within visual range of one another. When interacting with one table it was possible to see the visualisation appearing on the remote table easily in the periphery of vision. It became natural to look at the remote table when interacting with the local table. This was because all the visual 'action' was happening at the remote table.

During routine building maintenance at the lab, one of the tables was moved away from its regular position to the another part of the lab floor - so it was no longer with in eye-fall of the other table. This of course would be the case in a real world deployment where the tables would exist in separate households. With the tables now placed in this new configuration both tables were no longer in line of sight of each other. So in order to see if the system was working during a demonstration, it was required to step away from the original table and look over to another side of the lab. It became startlingly obvious that users living with a *Habitat* system may have no idea whether the system was actually working. This situation could arise from the fact that the remote user may not place any objects on their table, hence the local table would appear 'blank'. The local user may inadvertently forget that the furniture was 'live' and sending messages over the network, broadcasting their activities to a remote location, as placing objects on the table would not result in any direct feedback to the user. This notion of being unaware of transmitting information about personal activities in itself has a number of privacy issues that could detract from the use and adoption of *Habitat* in everyday use.

Two rough versions of local feedback visualisation were experimented with: the 'flash' and 'radar sweep'. A detailed description of these animations is provided in the previous chapter. The overall effect of the flash animation was far too distracting. The radar sweep animation did not look realistic and was deemed slightly unsettling during informal tests. In the flash and radar case the same effect was repeated for each interaction, whether adding or removing an object, it was felt that the system was conveying a the same feedback for two different actions. The feedback a user receives should be messages of reinforcement, confirming the system has understood the user's actions.

The local feedback visualisation selected for the final prototype was the ‘falling-floating’ animation. The effect of animation in use is particularly satisfying — when the user places the object over the table to put it down, the object identification subsystem detects it 15 centimetres or so before it hits the table surface. This means that visualisation of the object falling down is in time with the user’s hand movement of putting the object down. If the user places the object in the centre of the table, the outline of the projected image in the visualisation will eventually cover the outline of the real object, and it appears that the projected image is falling into the object itself.

On removing the object, a grey-scale image of the specific object appears at full opacity in the centre of the display. This image quickly scales up from nothing to a large size (so that its edges no longer fit on the display), whilst reducing in opacity to nothing. The composite effect is one of the image floating up and out of the plane of the tabletop. Again this rising up of the visualised image is to some degree in keeping with the physical movement of the user’s hand. The use of colour in the local feedback visualisation is consistent with the use of colour in the remote visualisation — grey for removed objects, colour for added objects. This consistency reinforces the entire interaction metaphor for *Habitat* and aids the user’s understanding of what is going on.

The shortcomings of the two earlier feedback systems were identified. It was felt the that the ’falling-floating’ visualisation was less distracting and remained appealing over time compared to the two other animations. Also, being able to differentiate and reinforce the messages pertaining to which specific object was being manipulated (by using its image) and whether it was being added or removed (colour versus grey-scale) reduced ambiguity and was genuinely useful.

5.3 System Architecture

The system architecture element deals with the software and hardware elements of *Habitat* and embodies a model for the logical state of the system. At a basic level, the model maps input from the physical representations to output in the digital representations. The underlying system architecture, in terms of the organisation and design of the software changed many times during the prototype. This section chronicles some of the key tasks.

5.3.1 Speed Optimisations

The rapid prototyping style of developing *Habitat* meant that the system software was created incrementally. Often several different versions of the software were being developed during a prototyping stage in order to explore and test new ideas. During demonstrations, different versions of the code could be used. Previously frozen stable versions of software could be then used for important events with external visitors.

This allowed the development of many aspects of the system to be done in parallel, without hindering other aspects of the software. Eventually towards the end of development the code fragments needed to be consolidated to merge all the functionality into one single program. Although the system worked logically a problem was immediately noticed. Every few moments the system would freeze. The root of this problem was the code dealing with the tag-reading hardware. The tag-reader requires a certain fixed period of time before it is ready to communicate with the computer. Since the computer operates at very high speed compared to the much slower tag reader, it is necessary to tell the computer to wait for this time before it polls the tag-reader again for data. An instruction in the system software pauses the execution and waits for the tag reader to be ready again. Since all the code was integrated into the main program loop, the tag-reading code causes the graphics animation code to pause too, causing the freeze. The obvious solution was to separate the 'slow' tag reader code from the 'fast' graphics code into two separate programs that could be run simultaneously. This introduced an additional layer of complexity as the two programs must be run independently of each other but must pass messages between each other to co-ordinate their activities. Introducing these changes rectified the freezing problem.

Another efficiency was achieved by optimising the software routines that interface with the tag-readers. The tag-reading hardware has a fixed frequency in read operations, i.e. how quickly it can detect and identify which objects have been added or removed. The manufacturer recommends a minimum delay of 12 milliseconds between consecutive read operations. Sending consecutive read operations to the tag reader without waiting for this period will result in a 'time-out' error, early versions of the software performed read operations at every 500 milliseconds. After speed improvements were achieved by separating the tag-reading code and visualisation code into two programs, the delay in the tag reading was more noticeable. For instance if an interaction occurred just after the tag-reader had been polled with an inventory command, it would be another half a second before any effect/visualisation was seen. This is a very long time in terms of interaction design, where the aim is to make systems as responsive as possible. To counter this unsatisfactory effect the 'sleep' value, stored as a simple scalar constant in the code, was adjusted to 15 milliseconds. The effect on the system was to make it sleep for shorter periods and thus perform read commands more often, detecting objects more quickly. This solved the time lag issue and made the system feel greatly more responsive.

5.3.2 Selecting a Networking Protocol

Designing and developing efficient networking code was a key requirement. One problem that was revealed during the testing was that messages sometimes arrived at the server in the wrong order, causing the incorrect visualisation images on the remote side. The choice of communications protocols for the network code were between the two well-established Internet protocols, UDP (user datagram protocol) and TCP (transmission control protocol). The use of Internet protocols were chosen because they were robust, well established and the aim was to carry out real-world deployments.

TCP is analogous to a telephone conversation, where one party must set up a call and both must hang up afterwards. UDP is similar to postal mail, where a sender can send messages without having to set up a connection in advance. At first it was decided to go with UDP for the message-passing code due to its simplicity, low-overheads and speed when compared with TCP. However, occasional traffic congestion on the local network was responsible for the untimely delivery of some UDP packets that in turn was causing the erroneous behaviour. TCP automatically maintains sequence, therefore would eliminate this problem. Also, the speed penalty in setting up connections for TCP would be negligible for the small amounts of data being sent between our nodes on a local area network. Rewriting the network code to use TCP solved the problem with no noticeable reduction in performance.

5.3.3 Message Passing algorithm

Another flaw exposed during testing was that the performance of the system was rather sluggish compared to the prototype from the previous phase. The root cause of this performance issue was due to a poorly designed message-passing algorithm. The early versions of message passing software caused each node to continually send messages detailing all the objects currently on that table to the other node. This was causing ‘flooding’, a situation where an excessive volume of messages are transmitted, overloading the ability of the system to process the messages. The problem manifested itself as a noticeable lag between adding or removing an object and the remote visualisation reflecting the change.

The message-passing algorithm was completely overhauled. The new solution was more intelligent with its use of bandwidth, by only sending messages when an interaction occurred. The content of the message also changed, the system now only sent a list of items that had been added and removed since the last message. Each RFID tag has a unique identity, represented as a 20-digit hexadecimal number. This hexadecimal number is transmitted as a string over the network, each artefact requires 160 bits. Since the number of artefacts added or removed varies during use, the length of the messages are multiples of 160 bits. This is an extremely low bandwidth requirement for modern computer networks. These efficiencies allowed messages to be processed in much more timely manner, resulting in more responsive visualisations and much less bandwidth to be consumed.

5.3.4 Stuttering Visualisations

As discussed earlier, the system software maintained a logical model of all the interactions happening at each table. A dynamic structure is kept to maintain a historical record of each interaction. Each record of an interaction contains further structures and lists of information the artefacts RFID serial number, the time it was added and so on. This data is used to calculate values for animations such as opacity and scale. An oversight was made in selecting the format to encode time values, as the programming environment specified only integer values for system time values. When the software to animate the images was developed to use the encoded data structures for each interaction, instead of smooth animations it was found that the effects were stuttered. Eventually the fault was traced to the integer value of time used being fed to the graphics code. A change in the encoding format to store relative time intervals as real numbers eliminated the problems and restored smoothly animated visualisations.

5.4 Balancing Attention and Distraction

It is now pertinent to discuss some of the issues about awareness systems. The area of evaluating the effectiveness of ambient awareness systems has been neglected by researchers to date. This may be due to the complexity in evaluating human faculties of perception, awareness, distraction, foreground and background attention. The internal mechanisms of the mind regarding processing of multiple tasks and information feeds are not well understood.

In terms of the environment created by the *Habitat* installation, there are a range of foreground and background attentive states that can be supported. For example, a background and foreground can said to exist within the user's living space, in the vicinity of the *Habitat* installation. The scope of the foreground is around whatever task the user happens to be undertaking at the time. The background can be said to be the items not directly involved with his task and at the periphery of attention. For instance walls, paintings, furniture and fixtures. The visualisations of the remote activities therefore occur in the background of the user's attention. Since the visualisations change slowly, there is little chance of the user being visually distracted and interrupting his main task. At any point the user may glance at the *Habitat* installation to shift his attention of the visualisations to the foreground. This is much like how one may look at a wall clock to see what time it is.

What if *Habitat* wanted to draw attention to the remote user? At what point would this become distracting? For instance in the first context of the visualisations, the functionality could be altered so that when an artefact is added or removed the local user and the remote user receive the same foreground visualisation. In practice this may be the wrong thing to do. Consider the case where the two users are both at their tables and both about to place an item on the table. Playing the local feedback visualisation at both sides simultaneously would be confusing. Consider the situation where the remote user is in the second context, where the furniture is in the periphery of awareness. The local feedback visualisation is fairly 'lively' in its animation. This is fine for the user placing an object on the table, since for him the task is already demanding the foreground of his attention and the feedback visualisation is for reinforcement.

It may be that the actual equilibrium point of attention and distraction varies upon individual users and their circumstances at any given time. Factors such as temperament and mood may also take toll on how quickly the system can gain the user's attention or create distraction. Everyone's perception will be different and eventually some habituation to the visualisation will occur. The experience and feedback from developing and deploying *Habitat* has shown a number of noteworthy features in this regard.

Foreground visualisations that are fired when the user is directly interacting or looking at the visualisation can afford to be fast moving and rapidly changing. Such dynamism adds to the notion that the system is highly responsive and interactive. The local feedback interaction is an example of this case. The depth aspect of the visualisations are particularly important during the local feedback graphics, displayed when an artefact is added or removed from the table. The animations occur on the front-most layer, with the existing images denoting the activities of the remote partner are still visible toward the rear. The image of the artefact travelling in or out of the table visually mimics the user's movement of the artefact. By keeping the remote activities still visible in the back of the visualisation the user has the opportunity to not only process the local interaction but simultaneously perceive the remote activities. The user has the opportunity to reflect on his immediate activity in the context of the remote users activities.

The appearance or disappearance of an image also rated highly in grabbing users' attention. The properties of images themselves were also manipulated to have an impact on attention. The use of highly saturated, bright, full colour images at a large scale aided recognition and comprehension at a distance. Using high-resolution photographic images, with crisp edges make the visualisations easy to resolve. The change from colour to greyscale was easy to perceive instantly by the users. For background awareness the idea was not to distract but to draw the minimum of attention, whilst maintaining the impression that remote activity was ongoing. Using slow moving visualisations, images that gradually scaled up or faded away gentle non-distracting effects were created. The background of the visualisation is kept neutral, avoiding lines or textures. This creates empty space for the eyes to rest on which is known to be an important aspect of graphic design. In summary, foreground attention is optimised by fast moving, sharp colour images; background distraction is avoided by slow moving, muted images.

Many real world systems are multi-modal by their nature. Would adding other modes, such as sound be worthwhile to *Habitat*? Sound is often added to computer interfaces since it provides a good medium for feedback. If it were to be added then careful attention would have to be paid to how it would be incorporated into the system. The key point would be to add it in a harmonious fashion to the existing visualisation rather than impose distraction or annoyance to the user.

The installation thus far has been designed with a strong tilt towards clean and appealing aesthetics, hiding as much of the raw technology as possible. Too many sounds in the user's environment may become too distracting. Too few and the user may not notice the installation at all. Some intelligence could be used to make better use of sound. For instance a natural as possible sound should be chosen. The glass tabletops already provide for a satisfying ‘clunk’ sound when objects are put on the table — another form of local feedback. Synthesising this sound for the remote user would be much more desirable than using a standard computerised ’beep’ sound. Since the real life table only makes a ‘clunk’ sound when items are added, it may be better to reinforce this metaphor by only playing the ‘clunk’ when adding items. It should also be noted that when removing the physical artefacts from the table, no sound is made; therefore there is a case for no sound to be made for the virtual artefacts. The table lacks support for volume controls such as dials and knobs. A clever solution may be to monitor background noise levels in the environment and adjust the volume of the ‘clunk’ accordingly. Since the sound will become imprinted in the user’s minds causing them to look at the installation on hearing it, good time synchronisation between the changing graphics and the audio ‘clunk’ should be ensured.

5.5 Summary

This chapter has presented a detailed discussion and review of the elements and core characteristics of *Habitat*. The changes and improvements to the system suggested during development, testing and deployment are analysed with regard to their impact when integrated into the final prototype. The chapter ends with a high-level discussion of attention and distraction, an issue which if of importance to ambient awareness systems.

Chapter 6

Conclusions

6.1 Assessment of Contributions

The main purpose of this research has been to investigate the potential of using everyday household furniture as a medium for conveying awareness. The broader goal has been to develop an understanding the implicit communication patterns between people in long-distance relationships.

To this extent, *Habitat*, a system for providing awareness over a distance was built. In creating the system a number of areas of understanding the problem were developed. Firstly, a method to detect objects (and thus infer user activities) was developed as the basis of the interaction with the system. Secondly, a means of encoding and transmitting user activity information between networked nodes was developed. Finally, a number of techniques in visualising these interactions were developed to convey awareness of the remote partner. The findings discussed in the previous chapters support this hypothesis that the physical elements of a person's living space can be enabled to support awareness applications.

6.1.1 Review of Thesis Objectives

As previously discussed at the end of the chapter two, three objectives were extracted from the survey of earlier works. These points are reviewed in turn to ascertain the extent to which they have been met by *Habitat*.

1. **Create a bidirectional, reciprocal communication platform.**

   The defining characteristic of long-distance relationships is that people are separated by distance. This separation is generally spatial distance but may also contain an element of temporal distance. The solution developed is competent at bridging spatial distance since it supports a fundamental construct in human communication — presence. Each station is a carbon copy of the other, therefore encouraging reciprocal action. The system supports independent, simultaneous and bidirectional communication between each station. As a platform for communication this objective has been fulfilled. It was envisioned that with time users may employ their own symbolic language of sorts, assigning various meanings to the different activity visualisations of one another.

2. **Allow users to retain manual control of their participation and privacy, but don't let the system get in the way.**

   The objective was to design and build a system that provided a simple, intuitive common interface that would not impede the partner's daily activities. Using furniture as an interface is a novel idea and frees the user from interacting with a computer in the conventional sense. Using physical artefacts that people would use in their day-to-day activities to interact with the system allows for a very natural interaction. Since these objects would normally be placed on a table anyway, the interaction metaphor is simple and requires no learning. Local feedback reinforces the interaction and awareness of communication taking place. The actual ability of the furniture to be used as a table is not changed in any way. The privacy aspect is one that any ubiquitous computing technology that is integrated into people's daily lives should respect. The system does not transmit any information if the user chooses not to interact with it. The interaction is explicitly orchestrated by manual action and feedback is given when communication occurs. No personal information is transmitted over the network. The activity information transmitted is not in a directly human comprehensible form, therefore of no value to a potential eavesdropper.

3. **Aim to minimise computation complexity and bandwidth costs.**

   The activity information transmitted between nodes takes the form of short lists of identifiers. These identifiers specify which, if any, artefacts have been added or removed from the table. When no user interaction is taking place no information is transmitted. This strategy of only transmitting when necessary and only sending tokenised information greatly reduces the amount of network bandwidth required by the system. Sending live audio and video data across a network link, as with some other awareness systems, is orders of magnitude greater than *Habitat*. With regards to computation complexity, the load placed on each host computer is very low. The simple graphical manipulations of two-dimensional images as used in *Habitat* is performed with ease directly in the video hardware in each computer. This is far less complex than other awareness systems that may be required to extract, decode, segment or otherwise deal with video or audio streams in real-time.

The outcome of the work on a whole has been a success with respect to the above objectives. The results of capturing and conveying local actions to a remote viewer are in-line with the majority of previous research into ambient media systems. The findings from the research are limited to a certain degree by the lack of a formal evaluation. Although the system was installed and tested by a wide variety of people both inside and outside of a laboratory, no long-term trial was conducted with real-life couples.

6.2 Implications of the Work

6.2.1 Practical Applications

Referring back to the scenarios developed in the introduction chapter, there seems some potential that the use of a system such as *Habitat* could have an immediate positive effect on the quality of their lives. In the first scenario, Mark the student living overseas was having problems keeping in touch with his mother. *Habitat* would provide a simple means of conveying presence and activity information over a distance. This would provide the much-needed reassurance to his mother and also provide some indication of when they are at home and there available to talk on the telephone. The time difference between the two countries may not be such a big problem since they do not have a desire to synchronise each other's activities.

In the second scenario, David who works from home has developed the tendency to distract Tania at work. Since the use of *Habitat* does not exclude the use of other communication technologies, the problem may remain. There is a chance that given an alternative outlet to feel connected, David can be motivated not to interrupt his partner. Also Tania who previously tended to stay at work late may choose to come home a regular time as the richer sense of awareness provided by *Habitat* gives her the impression of being at home with David.

John, the oil-rig worker in the third scenario would be an ideal test candidate for *Habitat* because of the remote isolation of his environment away from home. The specific and natural interface would be particularly effective for people lacking confidence with computers and robust enough for the young child in the family to use to interact with her father. The low-bandwidth aspect of the system would be attractive in a situation where communication is limited.

6.2.2 General Recommendations

Several recommendations can be extracted from the realisation of the *Habitat* concept that can apply to awareness applications as a whole.

Keeping an Open Channel

Awareness applications have the scope to provide users with continuity in connectedness, a benefit that is derived from devices, networks and systems that are designed to be always on, always connected and always utilised. This paradigm was introduced with early *Media Spaces* work that provided open links between people in their office spaces. This is in contrast to the traditional telephony approach, where calls are only made when needed. This usage model arose out of a necessity of reducing costs and keeping the network lightly loaded. These issues no longer apply to modern computer networks. *Habitat* has low bandwidth requirements as it transmits short, encoded lists of object identifiers only when an user interaction occurs. The data transmission is not being sent in a constant stream but 'dribbled', that is a small amount of data is transmitted at irregular intervals. The connection to the remote node needs to be readily available. On a residential broadband network this presents no challenge since the nature of such a connection is like any other piped utility, always on and connected. The system would also be functional with a dial-up connection, but there were would a significant latency overhead in establishing the connection, transmitting the data and then clearing the call each time an interaction occurs. This would greatly detract from the underlying immediacy of knowing that the remote partner is interacting in a nearly real-time manner.

Create Appliances that Minimise Changes In User Behaviour.

This recommendation deals with the characteristics of the interface that the user is presented with. Rather than providing the user with a general purpose or ambiguous interface it is much better to provide a specific interaction metaphor using a specialised interface. Appliances are generally intuitive and require no special training to use. Appliances are generally designed to do one thing well, rather than a plethora of functions poorly. *Habitat* goes a long way toward this aim as it is a self contained unit that enables interaction using a well defined manner. Most people do not consider furniture to be an appliance, rather more as a regular fixture in the landscape of a home. This often leads to the majority of functional furniture becoming invisible in-terms interfering with everyday life in the home. By enhancing and extending furniture in the manner *Habitat* requires, whilst not interfering with its original purpose, a balance has to be maintained to not to greatly affect a change in the user's behaviour. For example, it would be discouraging to create an awareness appliance out of a chair that relied on projecting graphics on its seat — since these graphics could not be seen by the user when sitting on the chair.

It should be noted that *Habitat* does give cause for slight changes in behaviour. For instance, hovering directly over a table at certain angles can occlude the overhead projection and therefore block a part of the remote activity visualisation. Repeated adding and removing of objects, as occurs when drinking coffee, will result in the triggering of the local feedback visualisation. In addition, when a remote activity causes a visualisation on the table, the partner may feel compelled to put newly placed objects around those graphics or move existing ones so as not to overlap with the visualisation. For the vast majority of users these issues are probably not too distracting or unsettling. The task of developing a new system that is incorporated into everyday life that has zero impact on its users would defeat the objective of obtaining awareness.

Non-Distracting Awareness

In line with ambient media or calm technologies, it is recommended that awareness systems be designed with a minimum of visual or auditory distraction. Awareness is generally a low cognitive load process and any technological solution should maintain this.

Creating such systems to be 'non-distracting' is a subtle art, relying on expertise in many areas such as human perception, graphic design, animation and techniques for visualisation of qualitative information. A range of channels or senses can be engaged, either in combination or separately i.e. sound, touch, smell, heat etc. as well as the mainly visual medium that is employed by *Habitat*. The challenge lies within assessing the level of distraction. The system needs to alert users to new information to the user, perceived in a 'gentle' manner — but not so subtly that they might not notice it at all. It is also interesting to understand the balance of how information is consumed by users in the foreground of their attention and how that same information moves to the background of the overall awareness.

Awareness systems in general may benefit from a 'digital-wake' effect - where a trace or echo is left behind to convey an event that happened in recent history. This history element allows for a graceful fading transition from the actual activity adding to the non-distraction principle and also provides a means for the user to reflect back on the awareness information and infer general trends and rhythms.

Privacy

Privacy is an important consideration for all ubiquitous computing technologies. The potential for misuse of personal information could be a big concern for some users. There are several levels of privacy to be considered. On a system level it could be very undesirable for information on a user's behaviour to fall into the wrong hands. For instance, a party eavesdropping the communications from one of the tables could tell if there has been no activity for sometime, indicating that the person may not be at home. On a personal level, an individual may occasionally wish not to participate with the system.

The concept demonstrator developed does not protect privacy at a system level using robust techniques such as encryption, all information is sent in clear-text over the local network or the Internet. The issue was not dealt with during the prototyping as it was felt this type of protection of the data stream could be incorporated at a later date if was felt necessary. At the time, it was thought that the activity information would be of little interest to anyone outside of the relationship.

On the level of personal privacy, *Habitat* compares admirably against some of the earlier ubiquitous computing work. The shortcomings of those projects were based around issues of not providing users with satisfactory means to control the flow of their personal information. *Habitat* on the other hand has a number of tacit features that help to maintain user assurance of privacy, by virtue of the design of the interaction method employed. These elements help users maintain control of information about their activities. First and foremost, the connection being made is only between two nodes, each of which is a trusted party. Since the couple are already in a trusting relationship and the connection is made between their private living spaces, the system builds upon establish principles of trust and privacy in the home. The awareness information being transmitted is symbolic in nature and only information about activities is being conveyed. This is an order of magnitude less intrusive than a live audio/video link between two locations. Also the context of use of the system is controlled as it relies on the use of an installation of furniture in a fixed location. The scope for the communication device to fall into the wrong hands is limited. Users always have the option of not participating with the system by not placing tagged objects on the table.

Other issues regarding bad publicity surrounding auto-identification technologies such as RFID cannot be avoided. RFID technology has received some bad press from those concerned about civil liberties, consumer rights and the conspicuous tracking of people. The best policy would be to be up-front with the users and tell them what technology is being used, how it works and what information is being sent. Being clear and transparent would help the users feel more comfortable with the technology and allow them to make an informed choice. There is an element of hype surrounding any new technology which subsides with time once people have been giving the opportunity to weigh up real-life issues around its use. Often bad publicity comes from fear of new (ubiquitous) technologies.

Privacy should be a prime concern of awareness systems. Users should be made aware of what information is being transmitted and when. These aspects should be thoroughly explained before any deployment and the use of a feedback mechanism to show monitoring. The visualisation of the awareness information should relate to this information to make things more transparent. Users should have the option to opt out and not interact with an awareness system as they choose.

Health and Safety Issues

The issue of health and safety of is an important consideration when developing appliances to be installed in the home. If a technology is deemed unsafe then the possibility of any trials with the general public are impossible. In any project, there is an element of risk that needs to be managed. In the case of *Habitat* two areas can be highlighted for discussion.

Firstly, the physical aspects of the installation. The furniture needs to be assembled and fixed together properly and assessed with-in the users living space to ensure a suitable location. Connecting wires need to be recessed to mitigate the risk of a trip hazard. The projector needs to be fixed to the ceiling with the correct mounting to reduce the risk of it falling. The glass table-top may not be suitable for an environment with young children. Electrical standards for power supplies to all equipment must be adhered to.

Secondly, the tag-reading system uses radio waves to detect the objects. The equipment used by *Habitat* has an operating frequency of 13.56 MHz, power of 4 W and a maximum read distance of 20 cm. In recent years there has been much public concern with levels of electromagnetic radiation from electronic goods - especially radiation from mobile phones and their masts. The tag-readers used in *Habitat* confirm to international standards[1] on safety on field signal strength at distances from the antenna. These tag-reader systems have been certified not interfere with medical apparatus such as heart pacemakers.

Suggested recommendations are that installations should consist of suitable materials for the environment that they are deployed in, with appropriate care taken to fix sub-systems in place. Users should also be informed how identification systems such as the tag-reader work. Any potential hazards to health, however small, such as radiation from the antennas should be explained in simple and clear terms.

6.3 Future Work and Research

This section describes areas of further work that can be done to extend the functionality of the concept demonstrator or develop the field of research.

6.3.1 Improving Visualisations

A number of enhancements can be made to the visualisations to make the system more sophisticated. One area could be to introduce the idea of propor-

[1] IEEE C.95-1-1991, the standard for safety levels for human exposure to RF electromagnetic fields.

tional fading of the visualisations. For ease of development, the visualisation being currently used fades all images over a fixed duration. For instance, consider an example where a coffee mug has already been on the remote for one hour when a book is placed alongside it. The mug is removed and a few moments later the book is removed. The visualisation will show the both images fading away over a minute. The mug image, since it was removed first will disappear for shortly before the book image, even though the mug was 'active' for an hour compared to a few seconds for the book.

It may be worthwhile to change the visualisation so that when an object is removed from the table, the time it takes for it to fade away is proportional to the duration of its time on the table. An object that had been on the table for an hour would fade away more slowly than an object that was just placed for one minute. The underlying information to achieve this effect is stored in the Interaction List. There could be some limits put in place, so that there is a minimum and maximum fade duration. The duration of fading would convey extra element of information to the remote viewer, so they can have a deeper understanding of their partner's activities.

Currently the fading effect is linear and the objects opacity is reduced to zero proportionally with time. One suggestion is to make the fading non-linear so that on object removal, the image turns grey-scale and fades quickly to some arbitrary amount and then the rest of the duration of the fade is much slower. This functionality might make it easy for a user to spot that a change has occurred than the previous linear fading system, where the visualisation is obscured with images of previous objects.

Alternatively following the concept of keeping a daily history of the remote activities, each image could be kept on the display for the duration of a day. Fixed levels of opacity could be arranged on a continuum, so that new activities are 100% opaque and the previous activities drop their opacity levels to compensate. Using this method of visualisation, new items placed on the table would appear brightest, older items would appear duller (in order of the duration on the table). The concept could also be applied to removed objects, so that the most recently removed objects would appear grey-scale but fully opaque, whereas the objects that were removed the longest time ago would appear grey-scale but with reduced opacity.

Already described above is the random placement scheme for image visualisations. There is always a possibility that over time an image object may be placed over an existing image. There is also a chance that a new image object may be placed sufficiently close to a previous image to occlude it during its scale up period. A smarter algorithm for image placement could be implemented, where the Interaction List is traversed to find out where existing images are already. Thus the algorithm would only place new images in the blank spaces on the display. Further enhancements could make the placements appear balanced so that the images make best use of the display area. Attention must be paid so that the image placement remains random since making it too predictable may reduce the users interest in viewing new awareness information after prolonged use.

One may argue that an object that is static holds less meaning that items that are used frequently. For instance, leaving a book on the table for a few days may really just mean that it is being stored there, rather than the partner actually reading continuously during that period. A better inference engine could be developed to capture the users' activities.

6.3.2 Improving Object Detection

The size and power required by tag-reading systems can vary a great deal and are usually designed with specific applications in mind. A standard gate antenna with a specific read range and field of operation was incorporated into each table. Although this worked satisfactorily for *Habitat*, a custom engineered antenna may be have been better suited to give coverage over the whole table surface and improve overall reliability in object detection.

The antenna used was a lot smaller than the table surface; this meant that objects placed on the edge of the table were not always read. Due to the nature of this antenna and the power and frequency of the radio field used by the tag-reading system, the read range extended to approximately 15 centimetres above the surface of the table. The system would detect the object before it touched the table, or if an object was swept over the surface of the table. One could argue that an object is not on the table until actually touches the surface of the table. In reality the point the tag is detected matters (or the sweeping over the table situation is something that would occur very often in real life). As described earlier in the local feedback section, the object being detected coming into 'land' is desirable. The situation to the contrary when an object is removed is not so ideal, as the object has to be lifted clear of the read range before it is registered as being off the table. But as stated these points are moot as from observations during various deployments it was noted that people do not generally pause when adding or removing objects.

There are a number of methods to remedy this situation in the future. Firstly, to address the 'shape' of the field and provide the ability to read objects to the edge of the table, a custom antenna could be built. The manufacturer provides instructions on how both build the antenna and then tune it to work with the ISO-standard tags. The antenna requires a few basic components such as resistors and capacitors; the body of the antenna can either be constructed out of copper tape or tube (similar to copper pipes used in plumbing). An antenna meter is also required in the final tuning of the system. For our installation the antenna could be virtually invisible. The best approach would be to lift off the glass tabletop and use copper tape around the table rim (that the table top rests on) to form the body of the antenna. This would ideally provide a read area of the whole surface of the table.

In reality it may be better to bond the copper tape to a thin but relatively stiff square piece of sticky backed plastic. The plastic could either be transparent or a white, as this would enhance the characteristics the projection surface and it would be need to be stiff enough to hold the shape of the antenna. This would create a flat mat like antenna that could be wedged in between the table rim and tabletop. This solution would allow the antenna to be quickly removed or replaced in case of moving the installation or a fault with the antenna.

The issue of the read range is related to power, which in turn is related to the size and frequency of the receiver used by the tag reading system. By reducing the power output by the tag-reading system it would be possible to reduce the read range so that objects have to either come very close to the table surface or actually touch it. In practice this is somewhat difficult to achieve accurately. External factors such as other radio signals, metal infrastructure in the build, people, pets etc. interfere with radio fields, hence altering the read characteristics. Having more power allows the radio waves to penetrate further and allows us to read objects that are stacked on top of each other (like cups, saucers and plates) or items that are denser more reliably.

If the prime concern is to be absolutely sure exactly when an object was added or removed from the table then there are many possible solutions. For example, the RFID tag reading system could be augmented with another detection system based on contact switches or weight sensing. The reliability of tag-reader systems are high, they have been left running for weeks without any errors occurring. Occasionally the tag reader sometimes stops responding or tag reading times out. These glitches can be resolved by cycling the power of the tag-reader. The tag-reader interface software developed for *Habitat* allows a brief period of disconnection where this can be done without having to restart the main system software.

6.3.3 Exploring New Techniques and Technologies

There are significant opportunities for the results and ideas developed from awareness research to be an integral part of the next generation of communications systems. Current trends point to a future where a computation is cheap, bandwidth is plentiful and a population that is increasingly social and diverse in their communications needs. The use of ambient awareness devices and systems could reduce complexity and increase choice for the users. The general theme of awareness systems to fill the underlying and deep-seated needs of humans for communication and contact. Future research could follow a number of threads in the categories of capturing and conveying awareness information.

In line with work undertaken in *Habitat*, the recommendation is to capture and convey information in a unobtrusive manner as possible. A living space consists of many elements such as architecture, furniture, ornaments, keepsakes, art, appliances and lighting. Extending the work from tables, devices such as chairs, wall clocks, lamps and so on working in concert to provide an 'umbrella' of awareness in the home.

It would be worthwhile to investigate how such elements used for sensing and awareness around the home could enable and drive new applications. The field of 'telecare' aims to advance understanding of remote health monitoring and providing care and support to the elderly and infirm. Partnerships between universities, local governments and corporate research laboratories (notably BT and Intel) in this area have gained much ground in recent years.

Novel methods in conveying awareness are another area for future development. The majority of awareness systems in the past have concentrated on human perception in a single domain such as vision or sound. Interfaces that are multi-modal, engaging a number of senses in combination, are another area where much more research could be done. The use of touch, smell and even taste has been largely neglected so far and may provide a wealth of new and subtle interaction paradigms.

Research into the field of affective computing, using computers to measure external expressions of emotion could be extended to provide awareness to remote partners. Researchers in the affective field use the notion of 'virtual sensors' to measure human attributes such as stress or happiness. These virtual sensors are created through the fusion of several 'real sensors' that detect changes well-known biofeedback loops such as galvanic skin response, pupil dilation and heart-rate variability.

The fields of psychobiology also show evidence for biorhythms - a number of internal mechanisms that respond to changes in external factors in the environment including the presence and behaviour of other people. Investigation into technologies for mapping of these internal expressions and their impact on relationships and communication would be a hitherto uncharted territory of human connectedness.

6.3.4 In-depth User Studies

A number of questions have been raised during the development of *Habitat*:

- Does awareness of a remote partner improve the quality of a relationship? If the quality of a relationship can be said to consist of factors such as intimacy and reassurance, does having remote awareness help build or maintain these qualities? Does this reduce the loneliness and separation anxiety of the partners in being apart from one another? Can remote partners discover and understand rhythms, routines and patterns in a remote partner's activities?

- Does the possibility of constant awareness lead to a change of behaviour among partners?

- At what point does awareness switch from background to foreground of a person's attention? (and vice versa) Is there an optimum amount of awareness that can be achieved? At what point does background awareness become a distraction to foreground activity?

- Do people feel their privacy is being infringed when their environment is capable of sensing and reacting to their activities?

The most important area for future development of this work is in-depth user studies to help answer some of these questions. As of yet, no aspects of *Habitat* as have undergone extensive trials with a large number of users. Collecting this data is vital in order to evaluate the effectiveness of the system in providing awareness over distance.

One suggestion of a topic for a user study would be to assess the effectiveness of *Habitat* at providing awareness information compared to traditional communications technologies. The study would require the participation of a number of volunteers that are in long-distance relationships. There would also be a need for careful design of interviews, questionnaires and user diaries to capture qualitative data and feedback. Finally, a means of objectively measuring awareness during experiments would need to be developed and tested. This type of formal evaluation of ambient displays and awareness systems has been overlooked by most pioneers in the field.

Appendix A

Hardware Specifications

A.1 RFID Technology

A.1.1 Overview

Radio frequency identification (RFID) technology has been used in logistics and security applications for many years. Use of such technology is now gaining momentum as new radio frequencies are exploited (e.g. 2.45 GHz technology), new standards are agreed (e.g. ISO 15693) and cheap RFID tags are becoming available. Manufacturers and retailers have realised the benefits and substantial cost savings from using RFID in production and inventory tasks.

There are several classes of RFID systems that have developed over time, each has different characteristics and applications. The earliest type, electronic article surveillance (EAS) tags are used widely in anti-theft situations, for example in shops and libraries. These systems have the cheapest tags which are simple tuned circuits that can be detected in a radio field. They have the disadvantage of having no electronic identity the tag is either present or absent.

Subsequently, battery-powered 'active' RFID systems were developed for applications such as for vehicle tolling systems. These tags are the most expensive but have the best performance with ranges up to several hundred metres in some cases. Variants include vehicle key fobs that have additional features such as user controls to lock and unlock. There are a number of radio bands used worldwide e.g. 433 MHz. The RFID functionality is thus mixed with a telemetry application.

The third class of RFID technology, as used in *Habitat*, are 'passive' (battery-less) tags. They are powered by the radio field that is used to poll the tags and, in response, transmit back to the tag reader a unique identity pre-programmed during manufacture. They are relatively cheap (some are less than 1 UKP), have no shelf-life problems and can thus be embedded safely in artefacts, infrastructure and living things. The first mass application was in car ignition keys. The disadvantage is that the range is rather limited (2 m at best and 0.5 m for small format tags). Careful antenna engineering can offset the range problems so that it is possible to read a tag about a person or object reliably as it passes through a barrier such as a doorway.

The first available battery-less tags (TIRIS from Texas Semiconductors) used a very low frequency of 134 kHz. The more recent ISO15693 tags use a higher frequency of 13.56 MHz and have more intelligence within the microchips. These are available as cheap, small, printed flexible strips. Both types of tags are capable of storing information (c.f. an Internet cookie) that could also be of value in personalisation applications. The main advantages of RFID are that it is readily available, cheap and reliable. The progression of RFID ideas into next-generation barcodes means that is likely to be incorporated into just about any man-made item as costs continue to fall.

A.1.2 Equipment Specifications

TEXAS INSTRUMENTS

RADIO FREQUENCY IDENTIFICATION SYSTEMS

Data Sheet

HF Reader System Series 6000
S6550 Long Range Reader (Housed)

Specifications:

Part number	RI-STU-655A
Operating Frequency	13.56MHz ± 7kHz
Supported Transponders	Tag-it HF, Tag-it HF-I, ISO 15693 compliant Transponders
Power Supply	100 - 120V / 60Hz or 220 - 240V / 50Hz switch selected
Power consumption	Max. 60W
Transmitter power	0.5W to 10W ± 1dB (adjustable by software in 0.25W steps) above 4W output power an additional heat sink 0.8K/W is necessary
Transmitter modulation	AM (10% - 30%) ± 6% or 100% (adjustable by software)
Antenna connection	Basic antenna (TX/RX) 1 x SMA female Complementary antenna (RX only):: 1 x SMA female
Antenna Impedance	50 Ohm at 13.56MHz
Receive channels	ASK 423.75kHz and FSK 423.75kHz / 484.29kHz for both antennas (adjustable by software)
Communication Interfaces	RS232 or RS485 (set by jumper)
Address setting for interface	Optional: - 3-position DIP switch (up to 8 addresses) - Software (up to 254 addresses)
Communication Parameters	Up to 115kBits, 8 data bits, even/odd/no parity
Communication Protocol	ISO Host Protocol
Memory	EEPROM 1kByte (for parameters; up to 10,000 write cycles) RAM 256 kByte (for data) Flash 512 kByte (for firmware; update via communication interface)
Outputs	2 opto-coupled: 24V DC / 30mA 1 relay: 24V DC / 60W
Inputs	2 opto-coupled: max. 24V DC / 20mA
Synchronization	Protocol synchronization via I/O
Operating Temperature	-20°C to +55°C
Storage Temperature	-25°C to +85°C
Vibration	EN60068-2-6 (10Hz to 200Hz: 0.15mm/2g)
Casing	Powder-coated sheet steel, look-up hinged lid
Protection class	IP54
Dimensions (L x W x H)	300mm x 200mm x 160mm
Weight	5.5 kg

For more information, contact the sales office or distributor nearest you. This contact information can be found on our web site at: **http://www.ti-rfid.com**

Texas Instruments reserves the right to change its products and services at any time without notice. TI provides customer assistance in various technical areas, but does not have full access to data concerning the uses and applications of customers products. Therefore, TI assumes no responsibility for customer product design or for infringement of patents and/or the rights of third parties, which may result from assistance provided by TI.

Texas Instruments

Radio Frequency Identification Systems

Data Sheet

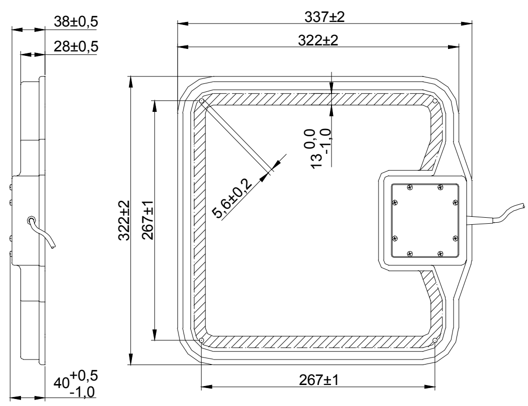
HF Reader System Series 6000

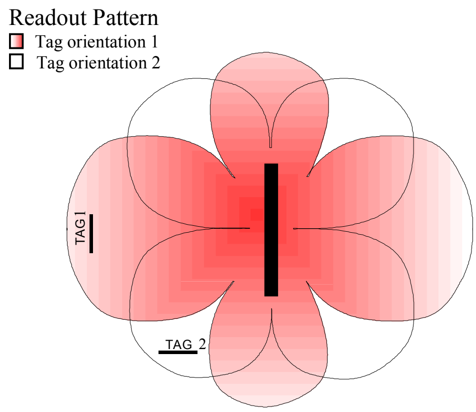
Gate Antenna

This antenna is a single-loop transmit/receive antenna with pre-set matching electronics for a transmitter frequency of 13.56MHz and impedance of 50Ω.

Specifications:

Part number	RI-ANT-T01A
Operating Frequency	13.56MHz
Impedance	50 Ohm ± 10 Ohm ∠ 0° ± 13°
Maximum RF power	8W
Operating Temperature	-25°C to +55°C
Storage Temperature	-25°C to +60°C
Case Material	Plastic ABS, black
Protection Class	IP65
Vibration	According to IEC-68-2-6 (10Hz to 150Hz: 0.15mm/2g)
Shock	According to IEC-68-2-27 (acceleration: 30g)
Dimensions (L x W x H)	337mm x 322mm x 38mm 337mm x 322mm x 40mm (incl. screw heads)
Weight	700g
Connector	SMA male (50 Ohm)
Cable	Type: RG58; Length: 3.6m ± 0.1m





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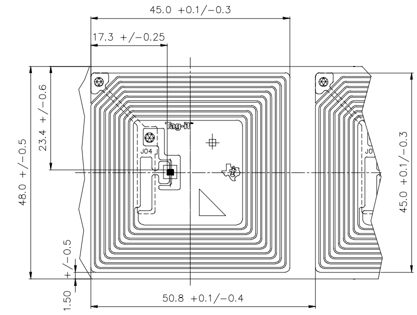
Tag-it™ HF-I Transponder Inlay
- Square -

The Tag-it HF-I Transponder Inlay is compliant with the ISO/IEC 15693 standard. With a user memory of 2k bits, organized in 64 blocks, the Tag-it HF-I Transponder Inlays allows advanced solutions for a variety of applications, including product authentication, ticketing, library management, supply chain management etc. The thin and flexible Tag-it HF-I Transponder Inlays can be easily converted into paper labels.



Specifications:

Part Number	***RI-I11-112A***
Supported Standard	ISO 15693-2,-3
Recommended Operating frequency	13.56 MHz
Passive Resonance Frequency (at +25°C)	13.86 MHz ± 200kHz (includes frequency offset to compensate further integration into paper)
Typ. required activation field strength to read (at +25°C)	98 dBµA/m #
Typ. required activation field strength to write (at +25°C)	101 dBµA/m #
Factory programmed Read Only Number	64 bits
Memory (user programmable)	2k bits organized in 64 x 32-bit blocks
Typical programming cycles (at +25°C)	100,000
Data retention time (at +55°C)	> 10 years
Simultaneous Identification of Tags	Up to 50 tags per second (reader/antenna dependent)
Antenna size	45 mm x 45 mm (~1.77 in x ~1.77 in)
Foil width	48 mm ± 0.5 mm (1.89 in ± 0.02 in)
Foil pitch	50.8 mm +0.1mm/-0.4mm (2 in)
Thickness	Chip: 0.355mm (~0.014 in) Antenna: 0.085mm (~0.0033 in)
Base material	Substrate: PET (Polyethylenetherephtalate) Antenna: Aluminum
Smallest bending radius allowed	18 mm (~0.71 in)
Operating temperature	-25°C to +70°C
Storage temperature (single inlay)	-40°C to +85°C (warpage may occur at upper temperature range)
Storage temperature (on reel)	-40°C to +40°C
Delivery	Single row tape wound on cardboard reel with 500 mm diameter Reel outer width: approx. 60 mm (~2.36 in) Reel inner width: approx. 50 mm (~1.97 in) Hub diameter: 76.2 mm (3 in)
Typical quantity of good units per reel	5,000

Note: For highest possible read-out coverage we recommend to operate readers at a modulation depth of 20% or higher
After integration into paper

For more information, contact the sales office or distributor nearest you. This contact information can be found on our web site at: **http://www.ti-rfid.com**

Nathan Table

Solid rubberwood legs with lacquer finish. Toughened glass top. Seats 2.

Cost: €125
Catalogue Number – 958381
W70 x H73 x D70cm

Nathan Chair

Solid rubberwood frame. Hand-woven hemp seat.

Cost: €55
Catalogue Number – 960740
W42 x H82 x D51cm
Seat height: 44cm

No Image Available

Nathan Stool

Solid rubberwood frame. Hand-woven hemp seat.

Cost: €35
Catalogue Number – 958382
W42 x H44 x D51cm

Items purchased from Habitat Stores – http://habitat.net

Appendix B

Software Architecture

B.1 Overview

The prototype consists of two networked computers running essentially the same *Habitat* system software (figure B.1). The form-factor of machines varied during development. Desktop computers since they were readily available, powerful and relatively cheap. For external deployments, Laptop computers were preferred since they were more convenient to transport and easier to hide away in a public installation.

The software was developed using *Isis* — a high-level, lisp-like, programming language optimised for prototyping high performance multimedia applications. Isis was developed with a 'lean and mean' philosophy, which allows it to run easily from the lowest specification PCs to high-end workstations. The small but complete syntax allows easy access to artists, novice programmers and experts alike to rapidly deploy full-featured applications. A number of built-in libraries allow access to input/output hardware, networking, sound, video and 2D-graphics.

Isis currently requires Linux or Mac OS X operating systems. The procurement and installation of *Isis*[1] is outside the scope of this thesis. During the development of the project, the *Habitat* system software was tested and deployed on both platforms.

[1] Details can be found at http://www.media.mit.edu/isis/

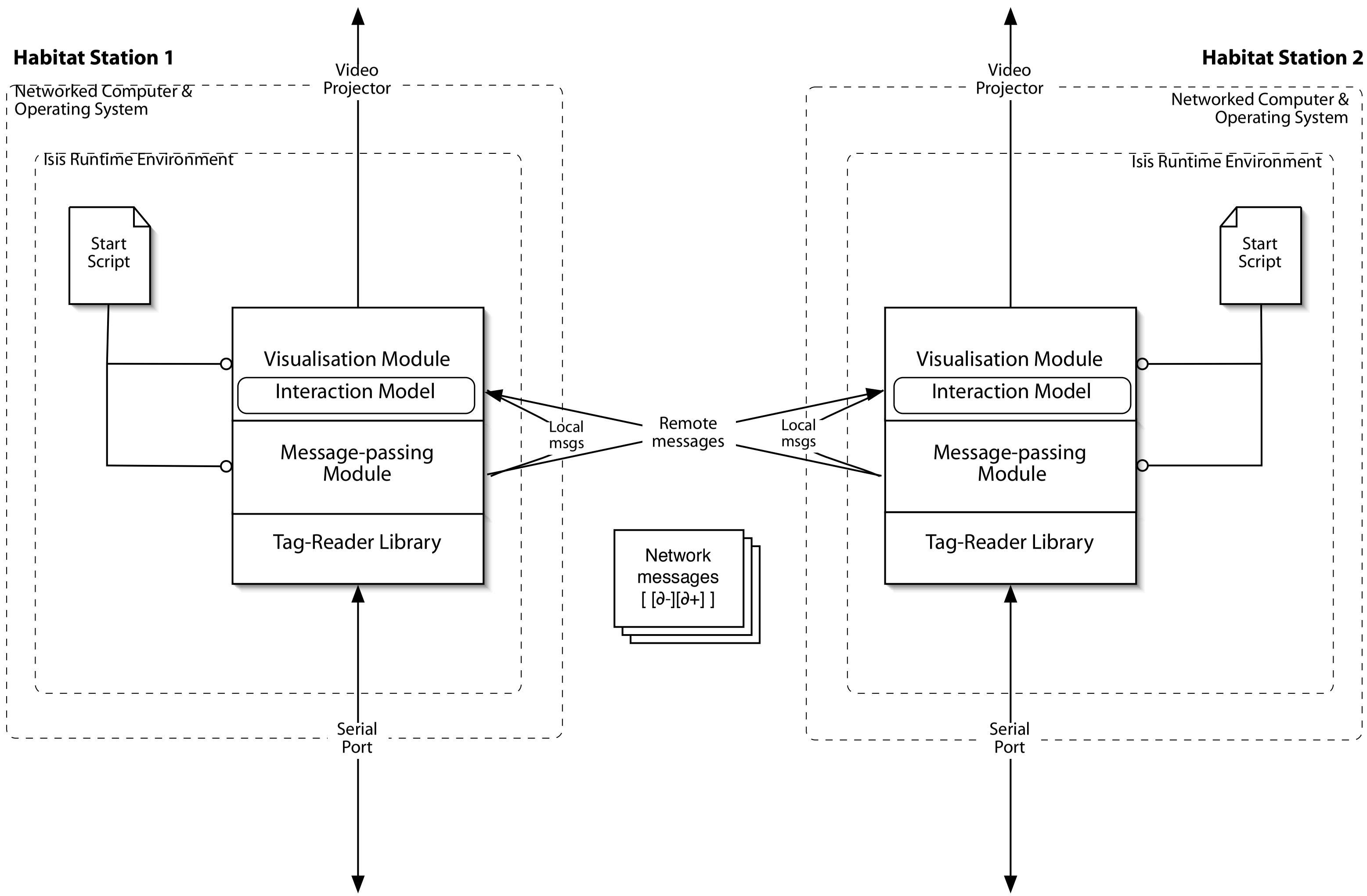


Figure B.1: Overview of Software Architecture.

B.2 Logical Data Structures

Each station is responsible for maintaining a model of user activities. Since each station must visualise the remote partners activities, these activities need to be communicated between stations.

B.2.1 Network Messages

Network messages are used to transmit each user's activity information between the stations. In-order to be a good citizen on the network, messages are only sent when necessary. The format of each messages is a list with two elements, each element of the tuple is also a list of arbitrary length. Each of these list elements denotes the artefacts that the user has removed or added to the table since the last message was sent:

$$[[\delta^-],[\delta^+]]$$

where δ^- is a list of tag serial numbers for each artefact removed and δ^+ is a list of tag serial numbers for each artefact added. In the case of no items being added (or removed) since the previous message, and empty list, [], is used a placeholder in the tuple.

B.2.2 Interaction Lists

On system start-up, data structures are created to keep track of interactions. Each interaction is time-stamped to keep a record of both past and present activities. Each station keeps a separate list of local interactions (artefacts added/removed locally) and remote interactions (artefacts manipulated by the remote partner). Maintaining two separate structures allows two kinds of visualisations: local visualisations for feedback and remote visualisations for awareness information. It also allows the system to be used by each partner simultaneously and simplifies the system logic. The Local and Remote Interaction Lists hold the same types of information. It should be noted that Local Interaction List of one station is logically equivalent to the Remote Interaction

List of the other — they both represent information about the same sequence of interactions but are visualised differently.

A structure is essentially a data storage construct that holds an unordered collection of names fields, each of which contains a value. The nature of structures allows easy query and modification of fields at anytime. Figure B.2 depicts the fields in an Interaction List. Each structure stores a record of a single interaction event (a single artefact is either added or removed). If multiple artefacts are manipulated then details of each artefact is recorded in a separate structure.

The fields stored in each structure are as follows:

TAGID. A string of length 20 characters representing the unique serial number of the RFID transponder tag attached to each artefact.

TRANSFORM. A pointer to an *Isis* graphics object. Each object is created dynamically with the filename of the image the artefact. Eventually the graphical object's attributes such as OPACITY, POSITION and SCALE will be manipulated to create the animations for the visualisations.

TIME_IN. This field records a time-stamp of when the artefact was placed onto the table.

TIME_OUT. This field holds the time-stamp of when the artefact was removed from the table. If the artefact is currently on the table then it is set to -1.

B.3 Software Components

B.3.1 Start Script

In order to start the software part of the *Habitat* system after booting the hardware, a simple start script was written. It should be noted that the keyboard and mouse are mostly redundant using a tangible user interface. The only

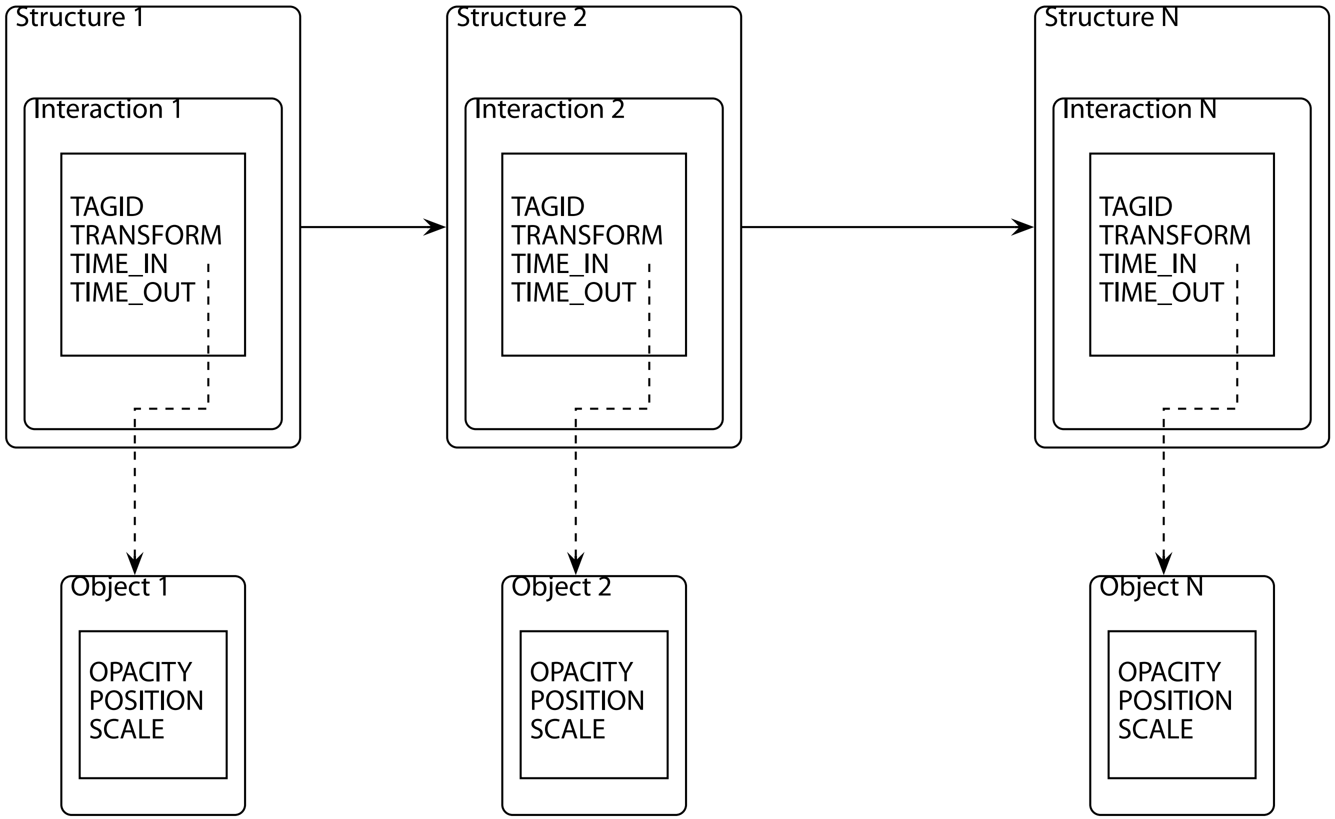


Figure B.2: The Interaction List data structure.

time the keyboard is used is when starting or stopping the system. The execution of the start script would be automated in a real-world deployment. The software can be quit and anytime by simply pressing the 'q' key.

The role of the start script is to launch to processes that are required to run simultaneously on each station: the message-passing module and the visualisation module. The script also optionally contains commands to allow the logging of various aspects of the output from these two software modules. One option allows the capture of historical data from interaction events to a file. Another option captures the output from the tag-reader for debugging purposes. Finally there is the option to log all the network messages that pass through the system.

B.3.2 Tag-Reader Library

This library was written to deal with low-level aspects of interfacing with the tag-reader hardware. The main purpose of the code is to carry out the 'inventory', the function of the tag-reader to read what RFID transponders are within range of its antenna. This task involves initialising the computers serial port to communicate correctly with the tag-reader hardware (setting the baud rate and parity). Memory buffers are created to efficiently send and receive binary information from the tag-reader. The tag-reader communicates using a specific protocol (ISO-15693) using coded packets. Routines to coded and decode these protocol packets, convert between human-readable ASCII and hexadecimal were also written. Finally communication with the tag-reader incorporates a cyclic-redundancy check (CRC) for data integrity which needed to be written. The manufacturer of the tag-reading hardware provides library routes to handle these aspects for the programmer. Unfortunately these were not easily portable to the UNIX systems used for *Habitat* so therefore had to be rewritten from scratch.

B.3.3 Message-passing Module

The Message-passing module is responsible for reading input from the tag-reader, determining whether new objects have been added or removed and sending messages to the local and remote visualisation modules accordingly.

1. Start.

   The module is launched by the Start Script.

2. Initialise Tag-reader.

   This is performed via a call to the Tag-reader utility library. This must be done before any communication with the tag-reader can take place.

3. Perform Inventory.

   A call to the tag-reader utility to read any tags that are present. Returns an empty list if no tags are available otherwise a list of strings, each string is the TAGID serial number of the present artefacts.

4. Calculate Changes.

   Each time the tag-reader is polled a list of tags is stored for comparison with subsequent reads. This allows the determination of whether any tags have been added or removed.

5. Changes?

   If there are new items that have been added or removed (a non-empty list) then a message is sent over the network both locally and remotely. The body of the message is $[[\delta^{-}],[\delta^{+}]]$

6. Wait

   A small fifteen millisecond sleep period is present to gear the speed of the computer against the relatively slow tag-reader hardware (as specified by the manufacturer).

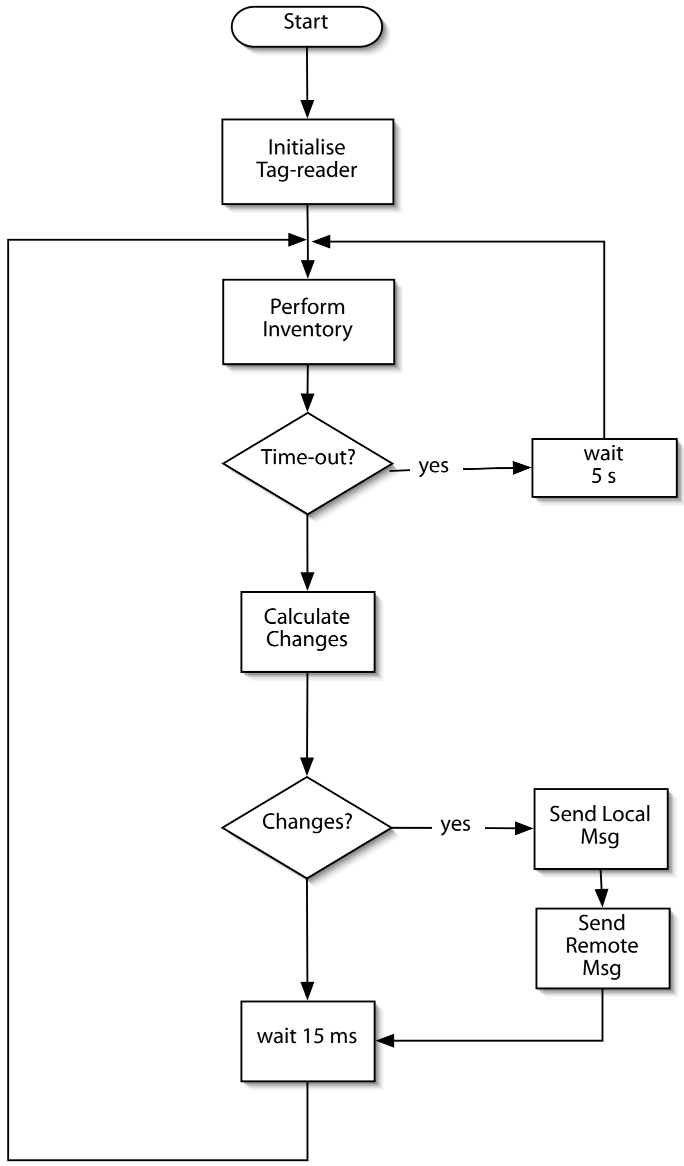


Figure B.3: Flowchart for the Message-passing Module.

B.3.4 Visualisation Module

This module is responsible for visualising remote activity information. It also provides local feedback visualisations. It receives local and remote messages over the network from the Message-passing Module. These messages are used to maintain an interaction model of remote and local activities. The data stored in these interaction lists are used to recreate animations that are displayed on the table-top.

1. Start.

   This module is launched by the Start Script.

2. Initialisations.

   This module contains a large number of data-structures that need to initialised. Network ports must be set-up before use (requires the network address of the remote *Habitat* station). Image files for the visualisations need to be mapped to the tag serial numbers so that correct artefacts can be identified. A Master-timer variable is initialised for use as a time-stamp in the Interaction List data structures and in calculations for the visualisations.

3. Check for Network Messages and Update Interaction Model.

   When a local message is received the message is split up to process δ^- and δ^+ separately. The Local Interaction List is changed to denote the addition and removal of artefacts. The same process is carried out in turn for remote message. The reason for dealing with local messages first is to provide immediate graphical response for the local user.

4. Render Scene.

   Each Interaction List structure is traversed. Active artefacts have graphical objects associated with them. Using the time-stamp to determine how long an artefact has been present or absent, the animation for each object is updated. The visualisation if of course different for the Local Interaction List compared to the Remote Interaction List. Objects that have been removed and have faded away (opacity is at zero) are removed from the render scene and no longer appear in the visualisation.

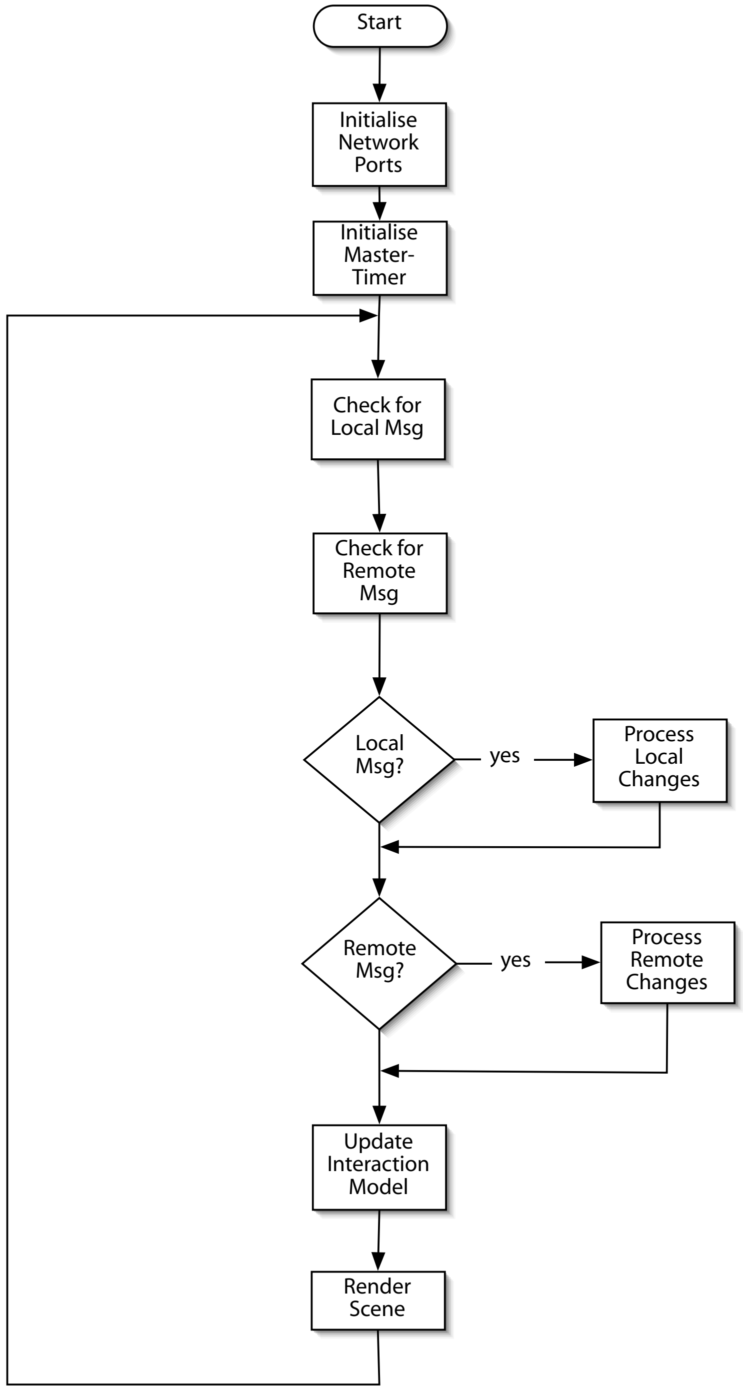


Figure B.4: Flowchart for the Visualisation Module.

Appendix C

Publications

1. Dipak Patel and Stefan Agamanolis, *Habitat: awareness of life rhythms over a distance using networked furniture*, **UbiComp 2003 Fifth International Conference on Ubiquitous Computing**, Seattle, 12 - 15 October 2003

2. Dipak Patel, *Habitat: awareness of daily routines and rhythms over a distance using networked furniture*, **Proceedings of LCS 2003 London Communications Symposium**, London, 8 - 9 September 2003, pp. 145 - 148

Habitat: Awareness of Life Rhythms over a Distance Using Networked Furniture

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ABSTRACT

The demands of modern working life increasingly lead people to be separated from loved ones for prolonged periods of time. Habitat is a range of connected furniture for background awareness between distant partners in just such a situation. The project particularly focuses on conveying the patterns of daily routines and biorhythms that underlie our well-being, in order to provide a sense of reassurance and a context for communication between people in relationships.

Keywords

Awareness, biorhythms, limbic regulation, connectedness, networked furniture

INTRODUCTION

Intuition leads us to believe people have an innate desire to have an up-to-date understanding of the emotional and physiological state of loved ones. When two people form a close bond, awareness of each other is essential to convey feelings and needs to one another and ensures that the relationship can survive and flourish.

Awareness of a partner's activities and biorhythms, such as sleeping, eating, socialising and working, is useful as these rhythms can be indicators of well-being - providing feelings of reassurance and connectedness, stimulating comparison and synchronisation between the pair-bond. The knowledge of any deviation from regular patterns and cycles is of equal significance.

Today our lives are enriched by pervasive technology that conquers distance to such an extent that the anxiety of being apart is minimal. But a corollary to technology mediated relationships is that people can still feel disconnected or not attuned with their partner, especially if they happen to be in different time-zones. Old-fashioned methods of keeping in-touch such as letter-writing are accepted as conveying a greater sense of intimacy but lack the instantaneity we are now used to. The majority of modern communications technology such as telephones, text messaging and e-mail, cause untimely interruptions, can be in-contiguous or can require a significant amount of effort to use while doing other tasks.

Habitat explores the potential of addressing these issues by using household furniture as a network of distributed ambient display appliances that centre on the capture and visualisation of daily rhythms to convey a sense of awareness between partners separated by distance.

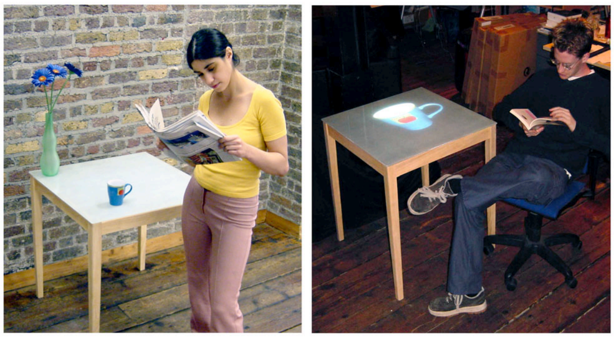

Fig. 1 - Habitat being used to link two distant partners.

BACKGROUND AND RELATED WORK

Research into the physiology of the brain is now starting to unravel some of the issues on why humans have such an affinity to one another [3]. The limbic brain, which was once believed to only co-ordinate sensations from the external world to internal organs, is now thought to be responsible for regulating our emotions. This mechanism for the mutual exchange and internal adaptation between two mammals, whereby they become attuned to each other's internal states is known as limbic resonance. This theory is developed further, proposing that the human nervous system is not autonomous or self-contained but an open-loop system that is continually rewired through intimacy with nearby attachment figures - a process of interactive stabilisation, known as limbic regulation.

The field of psychobiology provides us with a body of experimental evidence on biorhythms and their impact on our well-being [2]. Our biorhythms and internal body clocks are affected by a number of external factors, most importantly people we are bonded to.

Habitat also draws upon ideas from previous projects in ubiquitous computing that employ furniture and architecture as display devices, such as Ambient Displays [6], Roomware [5], Peek-a-Drawer [4] and The RemoteHome (exhibition - London/Berlin 2003).

TECHNOLOGY AND DESIGN GOALS

The initial range of Habitat appliances are in the form of two geographically separate, networked coffee tables.

Each station consists of a networked Linux computer, a RFID tag reader and a video projector.

Two people having a long distance relationship (Figure 1), use the Habitat system as follows: When objects (with a RFID tags embedded inside) are placed on the coffee table, they are sensed by the tag reader, which uniquely identifies each object. The tag reader is polled regularly by the computer to check if any items have been added or removed. Such events cause messages to be sent to the coffee table in the remote partner's living space. The remote coffee table displays a corresponding representation of the opposite person's activity (Figure 2) and their overall daily cycle on the surface of the table, using an appropriately mounted video projector. When items are removed, the displaying coffee table gradually fades away that representation.

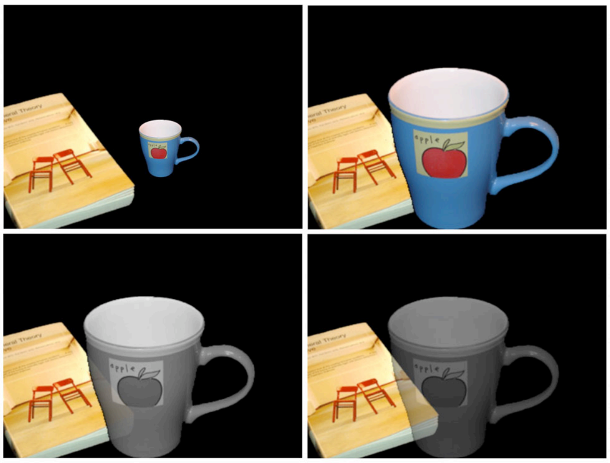

Fig. 2 - A typical sequence within a visualisation

Habitat takes into consideration several design guidelines in creating connectedness applications [1]: -

- The system should behave like an appliance that is always on and connected, to foster sense of continuity - an open link between the users.
- Participating with Habitat should require no change in the user's normal behavior and not alter the furniture's original use.
- The visualisations should be non-distracting, so they can be viewed across the room and in the periphery of vision without distraction. The visualisations are designed to indicate presence of the remote partner over a duration of time, so that observers are free to move around the living space and not have to constantly watch the display.
- The system should express the notion of a digital wake. A digital wake is a visual construct that allows the users to ascertain the history of previous interactions. When an activity ends, its representation gradually fades out but is never completely removed from the display. This gives users who return to their living space a mechanism to interpret what took place while they were absent.

Privacy and trust issues are dealt with implicitly as the furniture only connects into the personal space of a loved one, a person that a high level of trust is already shared with. Users are also made well aware of the specific artifacts that trigger the communication between Habitat stations. Reciprocity is important for limbic regulation, since each station is a duplicate, awareness flows in both directions in a continual feedback loop.

CURRENT STATUS AND FUTURE DIRECTION

The first phase of Habitat is complete, a proof of concept demonstrator system which acts as a platform for conducting experiments and extending ideas. A range of visualisations that describe remote activities have been created. A forthcoming trial will be used to determine the effectiveness and appeal of these different visualisations to potential users.

Future versions of Habitat will concentrate on the capture of more complex routines and activities. We plan to use biomedical technologies in concert with the connected furniture platform, to monitor users' body temperatures, heart rates and other well known metrics for tracking biorhythms with additional accuracy. Humans have several bodily rhythms that affect how we feel in addition to circadian rhythms, such as ultradian (~90 minutes), infradian (many days) and circannual (~1 year). There are also several environmental factors that alter or reset body clocks (known as zeitgebers) that could be accounted for within visualisations.

The aim of this research is to determine if we can successfully convey awareness of rhythms over a distance and if doing so can provide similar levels of reassurance and intimacy as physical proximity of partners in a domestic setting.

The eventual goal would be to install suitably evolved iterations of the technology with many groups of people outside of the laboratory environment and assess their use in a study - prime candidates being people who endure separation from family and partners for prolonged periods of time, such as off-shore workers or military personnel.

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5. Streitz, N. et. al., "Roomware: The Second Generation," in *CHI'02 Extended Abstracts*. ACM Press, 2002.
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Habitat

Awareness of Life Rhythms over a Distance Using Networked Furniture

The demands of modern working life increasingly lead people to be separated from loved ones for prolonged periods of time. Habitat is a range of connected furniture for background awareness between distant partners in just such a situation.

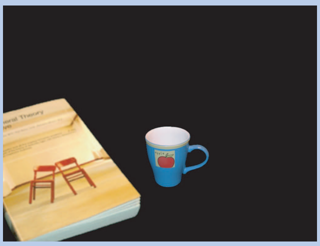
The project particularly focuses on conveying the patterns of daily routines and biorhythms that underlie our well-being, in order to provide a sense of reassurance and a context for communication between people in relationships.

The current Habitat system comprises two geographically separate, networked tables. Each table integrates a computer, an ISO-standard RFID (Radio Frequency Identification) tag reader, and a video projector.

Unique RFID tags are embedded in objects typically placed on tables at each site, such as cups, plates, books, and so on.

Placing these items on one table causes messages to be sent to the remote table, which displays a graphical representation of the objects. The system operates in both directions, conveying impressions of presence and activity around the tables at each site.

When items are removed, their representations at the far end fade away slowly, enabling in a single glance an impression of the recent history of events and overall daily rhythms around the far table. The system is designed to operate reliably 24 hours a day and can handle multiple tagged objects simultaneously at each site.



1 - She begins to drink coffee
[mug image appears]

2 - Continues to drink coffee
[mug image grows]

3 - She leaves the table
[mug image turns grey]

4 - Thirty minutes later...
[mug image fading away]

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Habitat: awareness of daily routines and rhythms over a distance using networked furniture

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Abstract: The demands of modern working life increasingly lead people to be separated from loved ones for prolonged periods of time. Habitat is a range of connected furniture for background awareness between distant partners in just such a situation. The project particularly focuses on conveying the patterns of daily routines and biorhythms that underlie our well-being, in order to provide a sense of reassurance and a context for communication between people in relationships.

1 Introduction

Intuition leads us to believe people have an innate desire to have an up-to-date understanding of the emotional and physiological state of loved ones. When two people form a close bond, awareness of each other is essential to convey feelings and needs to one another and ensures that the relationship can survive and flourish.

Awareness of a partners activities and biorhythms, such as sleeping, eating, socialising and working, is useful as these rhythms can be indicators of well-being - providing feelings of reassurance and connectedness, stimulating comparison and synchronisation between the pair-bond. The knowledge of any deviation from regular patterns and cycles is of equal significance. Today our lives are enriched by pervasive technology that conquers distance to such an extent that the anxiety of being apart is minimal. But a corollary to technology mediated relationships is that people can still feel disconnected or not attuned with their partner, especially if they happen to be in different time-zones. Old-fashioned methods of keeping in-touch such as letter-writing are accepted as conveying a greater sense of intimacy but lack the instantaneity we are now used to. The majority of modern communications technology such as telephones, text messaging and e-mail, cause untimely interruptions, can be in-contiguous or can require a significant amount of effort to use while doing other tasks.

Habitat explores the potential of addressing these issues by using household furniture as a network of distributed ambient display appliances that centre on the capture and visualisation of daily rhythms to convey a sense of awareness between partners separated by distance.

2 Background and Related Work

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Habitat also draws upon ideas from previous projects in ubiquitous computing that employ furniture and architecture as display devices, such as Ambient Displays [10], Digital Picture Frames [5],Roomware [8], Peek-a-Drawer [7] and The RemoteHome (exhibition - London/Berlin 2003).

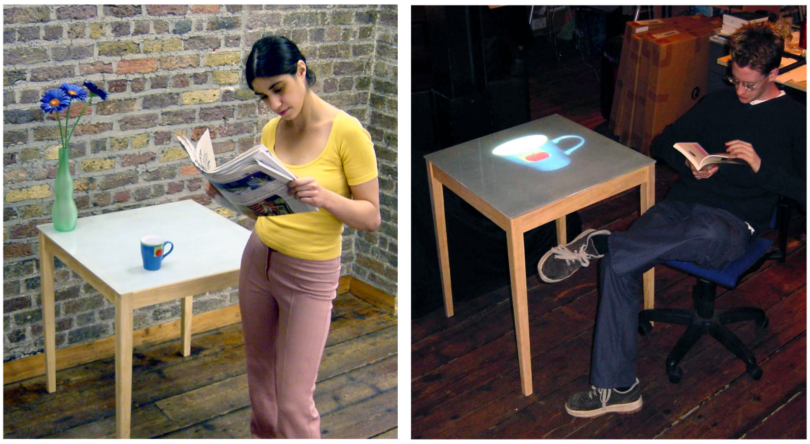

Figure 1: Habitat being used to link two distant partners.

3 Technology and Design Goals

The initial range of Habitat appliances are in the form of two geographically separate, networked coffee tables. Each station is consists of a networked Linux computer, a RFID tag reader and a video projector.

Two people having a long distance relationship (Figure 1), use the Habitat system as follows: When objects (with a RFID tags embedded inside) are placed on the coffee table, they are sensed by the tag reader, which uniquely identifies each object. The tag reader is polled regularly by the computer to check if any items have been added or removed. Such events cause messages to be sent to the coffee table in the remote partners living space. The remote coffee table displays a corresponding representation of the opposite persons activity (Figure 2) and their overall daily cycle on the surface of the table, using an appropriately mounted video projector. When items are removed, the displaying coffee table gradually fades away that representation.

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4 Proposed Experiments

The aim of this research is to determine if we can successfully convey awareness of rhythms over a distance and if doing so can provide similar levels of reassurance and intimacy as physical proximity of partners in

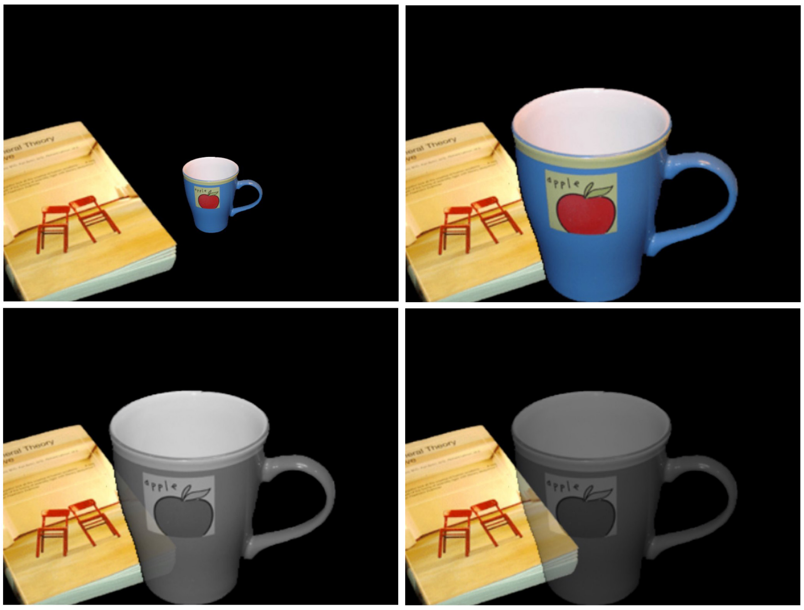

Figure 2: A typical sequence within a visualisation (clockwise from top right): remote partner begins coffee break, mug image appears (a), continues to drink coffee, mug image grows (b), ends coffee break, mug image turns greyscale (c), remote partner removes mug from table, image fades gradually fades away (d)

a domestic setting. We propose to use the Habitat prototypes as a platform for conducting experiments and collecting data to validate these claims.

In particular, we plan to use of questionnaires, interviews and observation, to investigate the following areas:-

- Reassurance - with extended trials we want to understand the level of reassurance provided by Habitat. Does such a system afford a sense of reassurance to its users? Are these levels of reassurance experienced equally by both members in the relationship? How does the experience of using Habitat vary from using conventional technologies such as the telephone?
- Continuity - how do we ascertain notions of continuity of awareness between partners? Can Habitat provide a sense of continuous connectedness between the partners? How can we measure this continuity, in situations where partners are using other technologies to communicate and convey well-being between each other (including word of mouth from other people)?
- Ambient awareness - how do we determine the extent of which habitat is a tool for non-distracting, background awareness? Do some types of visualisations fare better than others? Previous evaluations in this area [9] may only provide us with a limited set of leads or heuristics, but none the less, inform our work. How do we quantify the ability of the system to convey a sense of presence and duration [6], whilst in the periphery of our users' attention? What methodologies can we employ to allow the control of (real or perceived) changes in privacy [3] between the partners?

5 Conclusions and Future Direction

The first phase of Habitat is complete, a proof of concept demonstrator system which captures and conveys daily rhythms and routines over a distance. A range of visualisations that describe remote activities have been created.

Future versions of Habitat will concentrate on the capture of more complex routines and activities. We plan to use biomedical technologies in concert with the connected furniture platform, to monitor users body temperatures, heart rates and other well known metrics for tracking biorhythms with additional accuracy. Humans have several bodily rhythms that affect how we feel in addition to circadian rhythms, such as ultradian ($\sim$ 90 minutes), infradian (many days) and circannual ($\sim$ 1 year). There are also several environmental factors that alter or reset body clocks (known as zeitgebers) that could be accounted for within visualisations.

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Acknowledgements

This research was undertaken within the Human Connectedness group at Media Lab Europe with support from BTexact. Special thanks to Stefan Agamanolis, Fred Stentiford and Robin Mannings.

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Habitat

A range of connected furniture for background awareness between distant family members.

Aim

This project explores the role of awareness, intimacy and physical proximity in human relationships.

When two or more people form a close bond, awareness of each other is essential.

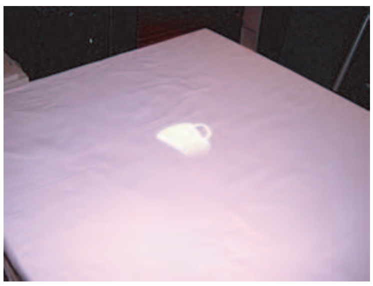
Awareness of each individual allows the members of the bond to convey feelings and needs to one another and ensures that relationship can survive and flourish.

People in a relationship have a innate desire to have an up-to-date understanding of the emotional and physiological state of their loved one. Awareness of patterns, such as sleeping, eating, socialising, working and well-being are particularly favoured as they allow means for discussion, comparison or even synchronisation between the members of the relationship.

Methodology

For the first phase a system comprising of two networked coffee tables has been built. Items placed on the table (in this case a coffee cup) cause a reaction at the remote end. Each table acts as an Internet appliance, with a low-cost, networked computer and RFID reader system embedded inside. Placing tagged objects on a table cause a message to be transmitted over the Internet which denote the users activities.

Applications



The data collected from these pilot studies would be used to develop novel applications in ambient awareness. A range of always on, background, distributed, applications are envisioned that provide reassurance and comfort as well as timely information for anyone that suffers from separation from their loved ones. Potential users would be parents and children, the elderly and extended families and travelling business people and their spouses.

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Appendix D

Press

Please refer to table on following page for a list of *Habitat* related press articles.

Date	Title	Publication and URL
30/05/03	Household goods furnished with technology of the future	Irish Examiner, Irish National Newspaper http://web.media.mit.edu/~stefan/hc/press/2003-05-30-Examiner.pdf
04/06/03	Brains Unboxed	IEEE Spectrum http://www.spectrum.ieee.org/careers/careerstemplate.jsp?ArticleId=c080603
24/10/03	Eenzaamheid verdreven via e-culture	Het Parool, Dutch National Newspaper http://www.parool.nl/artikelen/MED/1066972913030.html
25/10/03	Digitale emotie: Creatieve sector kan meer betekenen voor ICT	NRC Handelsblad, Dutch National Newspaper http://web.media.mit.edu/~stefan/hc/press/2003-10-25-NRC.pdf
28/11/03	Gizmo Puts Cards on the Table	Wired News http://www.wired.com/news/technology/0,1282,61265,00.html
28/11/03	Have Your Family Gather 'Round the Virtual Table	Slashdot http://slashdot.org/article.pl?sid=03/11/28/1836241&tid=
28/11/03	Poetry, technology and the subtlety of couplehood	Ni.Vu http://www.martinepage.com/blog/2003/11/poetry-technology-and-subtlety-of.html
01/04	Virtual Table Brings Distant Loved Ones Together	IEEE Distributed Systems Online http://dsonline.computer.org/0401/d/o1009.htm
02/04	Het hoeft niet altijd een computer te zijn...	Netwerk, Dutch Magazine http://web.media.mit.edu/~stefan/hc/press/2004-02-01-Netwerk.pdf
18/04/04	The Table Connection	We-make-money-not-art http://www.we-make-money-not-art.com/archives/000509.php

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